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EFFECTS OF DOMAIN-SPECIFIC KNOWLEDGE ON SOCIAL SCIENCES PROBLEM-SOLVING PERFORMANCE

by

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ABSTRACT

The study was to investigate the different effects of domain-specific knowledge upon the cognitive processes in social science problem-solving in higher forms in secondary education. The problem-solving process was reviewed from structured problems in physical science to ill-structured problems in social science. Based on the framework of Voss and his associates, the social science problem-solving model was developed. Subjects from Form 5 in secondary schools were grouped into high and low knowledge bases with reference to the results of the Knowledge Test concerning factual knowledge on industrial location. The subjects were further classified according to their general learning ability. Protocols on solving two industrial location problems were obtained. Statistical and qualitative analysis of protocols revealed that subjects of high knowledge base and subjects of low knowledge base employed different problem-solving strategies. The former decomposed the problems into sub-problems and handle these sub-problems one by one before proceeding to the final solution. The latter could also decomposed the problems into sub-problems, but followed a confusing path in making their solution. Only the subjects with high knowledge base and high

general learning ability could clearly identify and utilize constraints in the problem solving process. Reasoning arguments used in the problem solving process varied from high knowledge base subjects to low knowledge base subjects. However, reasoning arguments employed in problem solving seemed to associate with general learning ability but not knowledge base. It was found that semantic knowledge of the domain might not vary from one subject to another. The episodic knowledge of the domain permitted the high ability subjects to link and evoke the relevant and appropriate interconnected nodes of knowledge in the problem solving process. Even semantic knowledge nodes were found in the subjects of low ability, these nodes were fragmented and could not activate the surrounding nodes in the problem solving process.

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CHAPTER 1

INTRODUCTION

Recent years have witnessed a sharp resurgence of interest in cognitive processes. Some psychologists prefer to think of cognitive processes as the manipulation of mental symbols. A symbol or a group of symbols that stands for a class of objects or events possessing common properties is called a concept. A concept formation task can involve learning attributes which are relevant, the rule which is being used, or learning both attributes and rule (Matlin, 1983). Some cognitive psychologists tend to think of problem solving as the essence of cognition. They feel that cognition refers to ways of gathering and applying information in the pursuit of the solution to problems (Houston, 1986).

CONTEXT OF THE STUDY PROBLEM

Martorella (1972) classified concepts into different levels of difficulty. In the lowest level of difficulty, concepts are within a child's direct experience. Definitions of these attributes are always certain and direct. A "dog" and a "table" are examples of concepts of the "easiest" level of difficulty. On the other hand, some concepts, which are subsumed by many other concepts, are related to many other concepts. The attributes of these concepts are comparative and relational. One attribute may affect another or sometimes, all attributes interact each other. These concepts are classified as "very difficult". Many of the concepts of social sciences in higher secondary education, like "urbanization", "rural-urban migration", are of "very difficult" level. Although there has been a great deal of research directed towards the cognitive aspect of concept learning, concept formation and problem solving, most of the studies, like the works of Klausmeier (1971 and 1980) and Klausmeier and his associates (Klausmeier, Davis, Ghatala, & Frayer, 1969, 1974, 1975 and 1976) tends to focus on the formation of "easy" concepts. Relatively little has been done, however, on the "very difficult" concept formation in social sciences. Also, little is known about the application of the "very difficult" concepts in problem-solving in social sciences.

While problem solving in mathematics and physics (Chi, Feltovich & Glaser, 1981; Chi, Glaser & Rees, 1982; Larkin, 1983; Larkin & Reif, 1981; Larkin, McDermott, Simon & Simon, 1980; Simon & Simon, 1978; Tao, 1989) has been rather extensively studied, far less research has been done in chemistry (Heyworth, 1989). Furthermore, very little work has been conducted on social science problems (Armento, 1986). Chi and Glaser (1985) also claimed that there has been very little research done on social science problems. The author has searched the ERIC Index for the past ten years, up to 1988, and found that there were 7,208 studies in problem solving, 7,281 studies in cognitive processes, and 1,068 studies in social sciences. Out of these thousands of papers, only three papers involve studies concerning the cognitive processes of social science problem solving. The only interesting piece of work was conducted by Voss and his associates in economics problem (Voss, Greene, Post & Penner, 1983; Voss, Tyler & Yengo, 1983). Also, out of the M.A.(Ed.) theses in The Chinese University of Hong Kong, problem solving has been critically examined in relation to physics, mathematics and mathematical sciences (Kong, 1988; Lee, 1981; Wong, 1989). However, nothing has been done on social sciences problem-solving. In this context the investigation of the processes used in social science concept formation and problem solving, in relation to "difficult" concepts, becomes an attractive focus.

STATEMENT OF THE PROBLEM

The purpose of this study is to investigate the different effect of domain-specific knowledge and ability upon the cognitive processes in social sciences problem-solving in higher forms in secondary education. Moreover, the consideration of the study of problem-solving is twofold. First of all, an attempt is made to examine the processes of social sciences problem-solving. Secondly, this study tries to explore the differences, if any, that exist in individual differences on the procedures used, strategies employed and performance exhibited in social sciences problem-solving.

SIGNIFICANCE OF THE STUDY

It is hoped that this study can begin to answer some of the questions that educators may have, concerning the cognitive processes of how a social science problem is solved and the effects that the variables --- knowledge and ability, on the pupil's performance in problem solving. It is expected to obtain insights into the variation in the difficulty of a problem in relation to performance in problem solving. It is found that the role of problem-solving in social science subjects in secondary schools is becoming more important. Role play simulation involving problem-solving and decision making are encouraged to be one of the learning activities in geography classes (Curriculum Development Committee, 1983). Cox (1984) further suggested that appropriate use of problem-solving and decision making would provide students with opportunities to develop critical thinking skills. Law and Smith (1987) provided a good example of how problem-solving could be incoporated with classroom learning. They tried to use decision-making and problem solving as a framework in their book for Advanced Level geography students (Law & Smith, 1987). It is therefore hoped that the findings of this study would be relevant to the learning situations found in social studies, geography and economics classrooms.

On the other hand, social studies instruction may be considered within a general problem solving framework. Voss (1986) suggested a problem solving framework involving the information processing system of thinking for social studies instruction. His framework is represented in figure 1.1. It is therefore hoped that this study, using the problem solving approach, may be beneficial to the further studies of instructional design and implementation in social subjects in secondary schools.

Moreover, as this study tries to explore the relationship between individual differences in knowledge and ability and difficulty of problem, it is hoped that the findings of this study will be helpful to teachers tackling the problem of individual differences in learning situations, pooling together the teaching and learning resources and, designing curriculum. Within the skeleton of school based curriculum, the role of teachers changes from syllabus interpreter to curriculum maker (Fien, 1984). This will demand the development of new awareness on students' learning skills and processes so that appropriate

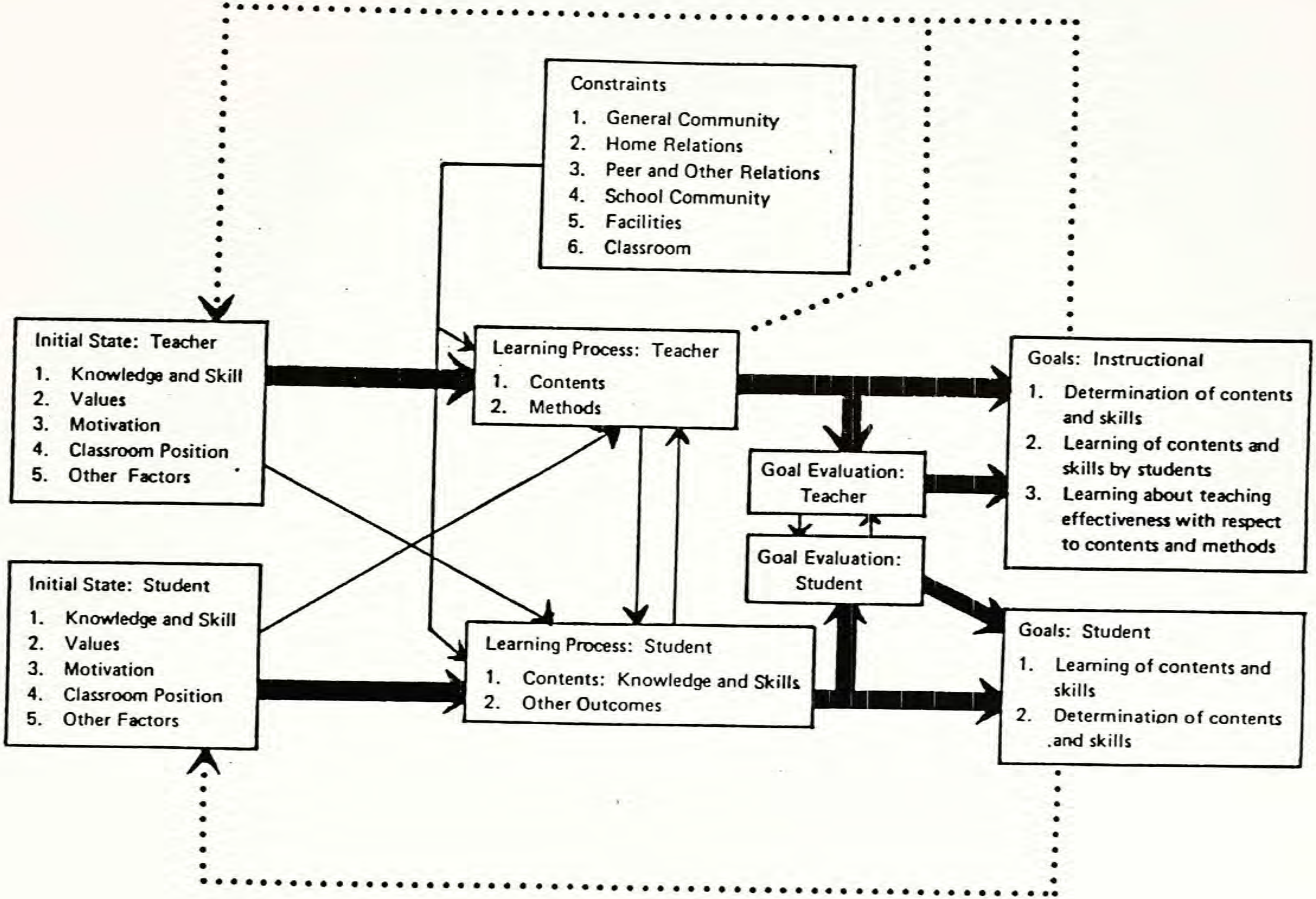

Figure 1.1. Diagram of social studies instruction considered within a problem-solving framework. (After Voss, 1986)

teaching strategies may be used. In addition, this study attempts to stimulate researchers to further investigate the possibilities of developing relevant and meaningful curricula of social sciences subjects, which employ problem-solving as tactics, allowing active participation of students.

CHAPTER 2
REVIEW OF LITERATURE

FROM CONCEPT FORMATION TO PROBLEM SOLVING

Definition of Concept

"Concept" is one of those terms that we use very often in everyday language. With reference to psychology, a concept refers to making the same response to a group of objects that share similar characteristics. Thus a concept is a way of categorizing objects and demonstrating objects which are related to each other (Matlin, 1983). With reference to the context of social sciences, a concept is defined as a kind of unit in terms of which one thinks; a unit smaller than a judgment, proposition, or theory, but one which necessarily enters into one of these (Gould, and Kolb, 1964). However, concepts may be referred to experiences, for instance, experiences of physical objects and relationships and experiences of personal qualities and social relationships (Bolton, 1977).

Concept Formation in Social Sciences

Bolton (1977) pointed out that there are two major and apparently conflicting theories of the nature of concept formation - the theory of abstraction and the theory of hypothesis testing. The traditional theory, known as the theory of abstraction or the "copy theory", is that concepts are formed by the subject abstracting certain resemblances among otherwise dissimilar stimuli. In the concept-learning situation the subjects must learn to discriminate among a number of different stimulus values, learning to respond to only one of them.

Stanley (1985) proposed an opposing point of view that a concept is formed by having a particular hypothesis about certain features of his environment. According to the theory, people kept track of several alternate hypotheses in assertion to the working hypothesis. This hypothesis-testing model viewed the concept learner as an active problem solver during the concept formation process.

Millward (1980) posited a computational theory of concept formation which accounts for the learning of abstract concepts such as one finds in social science education. One learns about a concept via experiences which are coded by elaborate mental entities, that is, frames, scripts and schemata. It is impossible to form abstract concepts, like social studies concepts, solely on the basis of features. Millward (1980) stated that for all such concepts, we had special frames, sequences of expectations, actions, facts, rules of behavior and so forth, and when the term (for the concept) was used, these frames were called out to be matched to the current state of the world. These matches did not have to be perfect and there are cognitive options for adjusting incorrect assumptions. Thus learner looks for certain kinds of contexts and uses frames to inject reasons, motives, and explanations for them. This schemata definition of concepts has no simple rule based on features, no set of defining features, and no prototype.

With some more concrete social concepts one might still apply the classical definition and related instructional strategies. In fact, limitations were recognized in abstract concepts (Stanley & Mathews, 1985). Moreover, Martorella (1972) noted that the area of social studies was certainly fraught with complexity with respect to concept learning due to the nature of the concepts it embraced. Concepts of the type, like "legislation" and "industrialization", that make up the disciplines of the social sciences are the most difficult of all. Apart from the traditional concept formation considerations, Martorella (1972) included three additional models for the social studies. These three models were "concept attainment" model, which consisted of leading students to develop their own knowledge by associating related kinds of knowledge in context; the "concept augmentation" model, which was to expand and deepen students' understanding of a concept of which they already had some knowledge; and the "concept demonstration" model, which involved initial expansion of knowledge, followed by association of related parts of knowledge in appropriate contexts.

Problem Solving in Social Sciences

In a sense concept formation can be thought of as an example of problem solving. The problem is to learn the concept, or to acquire the ability to identify examples of the concept correctly (Houston, 1986). The ability to solve problems is perhaps the most important product of learning, inasmuch as a person who is capable of solving problems can learn independently (Klausmeier, 1980). The means of attacking problems and acquiring, processing, and remembering information may be called strategies. Concepts, principles, and strategies are used in solving problems.

Besides, Voss (1988) developed a reasonable idea of the nature of learning, the concept of learning should be viewed as a transfer because how readily we acquire new information is so profoundly influenced by what we already know and can do. The general information-processing model of problem solving, especially as applied to ill-structured social science problems, provides a general conceptual framework for the study of learning, the model being especially useful when considering learning in academic subject-matter domains. Details of problem solving are discussed in the following sections.

Definition of Problem

We defined a problem as something that exists when a motivated organism is trying to reach a goal but is blocked from doing so by an obstacle or obstacles (Houston, 1986). A problem may be defined in another way that it is a situation in which you are trying to reach some goal, and must find a means for getting there (Chi & Glaser, 1985). Problems cover enormous range of difficulty and complexity, but they do have something in common. Matlin (1983) considered that there are three essential aspects of a problem: first, the original state; second, the goal state; and third, the rules. Chi and Glaser (1985) named the three aspects as the initial state, the goal, and the constraints.

The original state or so called the initial state is the situation at the beginning of problem solving. That means the problem begins in a certain state with certain condition and information. The goal or the goal state refers to the condition which is reached, when the problem is solved. It is the desired or the terminal state of the problem. The rules or the constraints are the restrictions, which may be numerous, that must be followed in proceeding from the original state to the goal state.

Kahney (1986) further noted that problems had two things in common. First, they all specify a "goal". Secondly, in each case the solver is not immediately able to achieve the goal. These facts can be used as a basis for a definition of the concepts of "problem" and "problem solving". Whenever you have a goal which is blocked for any reason, you have a problem. Whatever you do in order to achieve your goal is problem solving.

However, Mayer (1983) pointed out that any definition of "problem" should consist of the three ideas that (1) the problem is presently in some state, but (2) it is desired that it be in another state, and (3) there is no direct, obvious way to accomplish the change. This definition is broad enough to include problems ranging from geometry (Greeno, 1977, 1980c) and chess (Newell & Simon, 1972) to riddles (Reitman, 1964).

Understanding the Problem

Greeno (1977) pointed out that understanding was a constructive process, in which a representation was developed for the object that is understood. According to Greeno (1977), understanding the problem involves constructing an internal representation. Greeno believed that understanding had three requirements: coherence, correspondence, and relationship to background knowledge. A coherent representation is a pattern that is connected, so that all the parts make sense. Greeno also proposed that understanding required a close correspondence between the internal representation and the material that is being understood. Finally, Greeno suggested that good understanding was that the material to be understood must be related to the understander's background knowledge.

According to Simon (1983), problem solving may be understood from three view points. First of all, one may view problem solving as search. Solving a problem consists in searching the model of the space, moving from one node to another along links that connect them until a treasure is encountered. Secondly, problem solving may be viewed as reasoning. Since solving the problem consists in accumulating more and more information by inference until answer to the problem has been found. Thirdly, problem solving may be viewed as constraint satisfaction. Solving a problem consists in narrowing down the original set to a subset or unique object that satisfies all of the constraints.

Theoretical Frameworks of Problem Solving Research

There are four major approaches in the analysis of human solving phenomena (Greeno, 1978a; Rowe, 1985). These four theoretical frameworks are the Gestalt approach, the behaviorists approach, the psychometric model, and the information processing approach. Rowe (1985) gave a detailed explanation in his book.

The Gestalt Model Classical Gestalt psychology is generally regarded as the oldest of the interpretative frameworks within which problem solving was investigated. According to the Gestalt psychologists, the process of problem solving is a search to relate one aspect of a problem situation to another, and it results in structural understanding --- the ability to comprehend how all the parts of the problem fit together to satisfy the requirements of the goal. This involves reorganizing the elements of the problem situation in a new way so that they solve the problem (Mayer, 1983). Thus, the problem-solving processes consist of transformations which the configuration of the task undergoes. Changes in the problem solver's perception of the task eventually lead to a solution (Rowe, 1985).

<u>The Behavioral Model</u> In contrast to the framework of Gestalt psychologists, whose main concern related to perceptual set, behavioral theory attempted to describe and explain the determinants of the problem solver's response. The interpretation of problem solving within a behavioral framework emphasizes trial and error behavior, habit family hierarchies, responses established by operant conditioning, chains of association and transfer of learning. One of the shortcomings of the behavioral approach is that all interpretations of research findings are based on the assumption that complex cognitive processes follow the same laws of conditioning as simple examples of learned behavior do (Rowe, 1985).

<u>The Psychometric Model</u> Rowe (1985) suggested that psychometric studies and models tend to focus on the products of behavior rather than on the performance itself. Psychometric models are based on correlations. Certain intelligence characteristics predetermine the subject's problem-solving performance.

The Information Processing Model   Of more recent origin than the preceding three approaches to the study of problem solving is the framework of information processing research (Rowe, 1985). The work of Newell and Simon and their information processing theory (Newell & Simon, 1972) constituted a major breakthrough in the study of problem solving, and in research into cognitive processes in general. Information processing theorists relate problem solving to the form with which information is received, stored, and transmitted. They conceptualize human mind as an information processing system capable of manipulating symbols, switching methods and representations, and making decisions (Newell & Simon, 1972; Sternberg, 1982). Information processing model is employed in this study. Details of the problem-solving consideration in relation to information processing model are discussed in the following paragraphs.

INFORMATION-PROCESSING THEORY OF HUMAN PROBLEM SOLVING

All humans come equipped with an information-processing system, such as a long term memory for storing information permanently, a short-term memory for holding information we are actively thinking about, and processes for acting on that information (Mayer, 1983). According to Newell and Simon's (1972) theory and Simon's (1978) theory, human behavior can be viewed as an interaction between an information-processing system, the problem solver, and a task environment. In other words, these three components - information-processing system, task environment and problem space - establish the framework for the problem-solving behavior. These two theories and the three components are reviewed one by one below.

Newell & Simon's Theory of Representation

Newell and Simon (1972) put forward the famous problem solving theory which is directly related to human problem-solving. Figure 2.1 provides a picture of the general problem-solver as portrayed by Newell and Simon (1972).

Referring to their theory (Newell & Simon, 1972), an initial process produces inside the problem solver an internal representation of the external environment, at the same time selects a problem space. Once a problem is represented internally, the system responds by selecting a particular problem solving method. A method is a process that bears some rational relation to attaining a problem solution, as formulated and seen in terms of the internal representation. The selected method is applied: which is to say, it comes to control the behavior, both internal and external, of the problem solver. When a method is terminated, three options are open to the problem solver: (a) another method may be attempted, (b) a different internal representation may be selected and the problem reformulated, or (c) the attempt

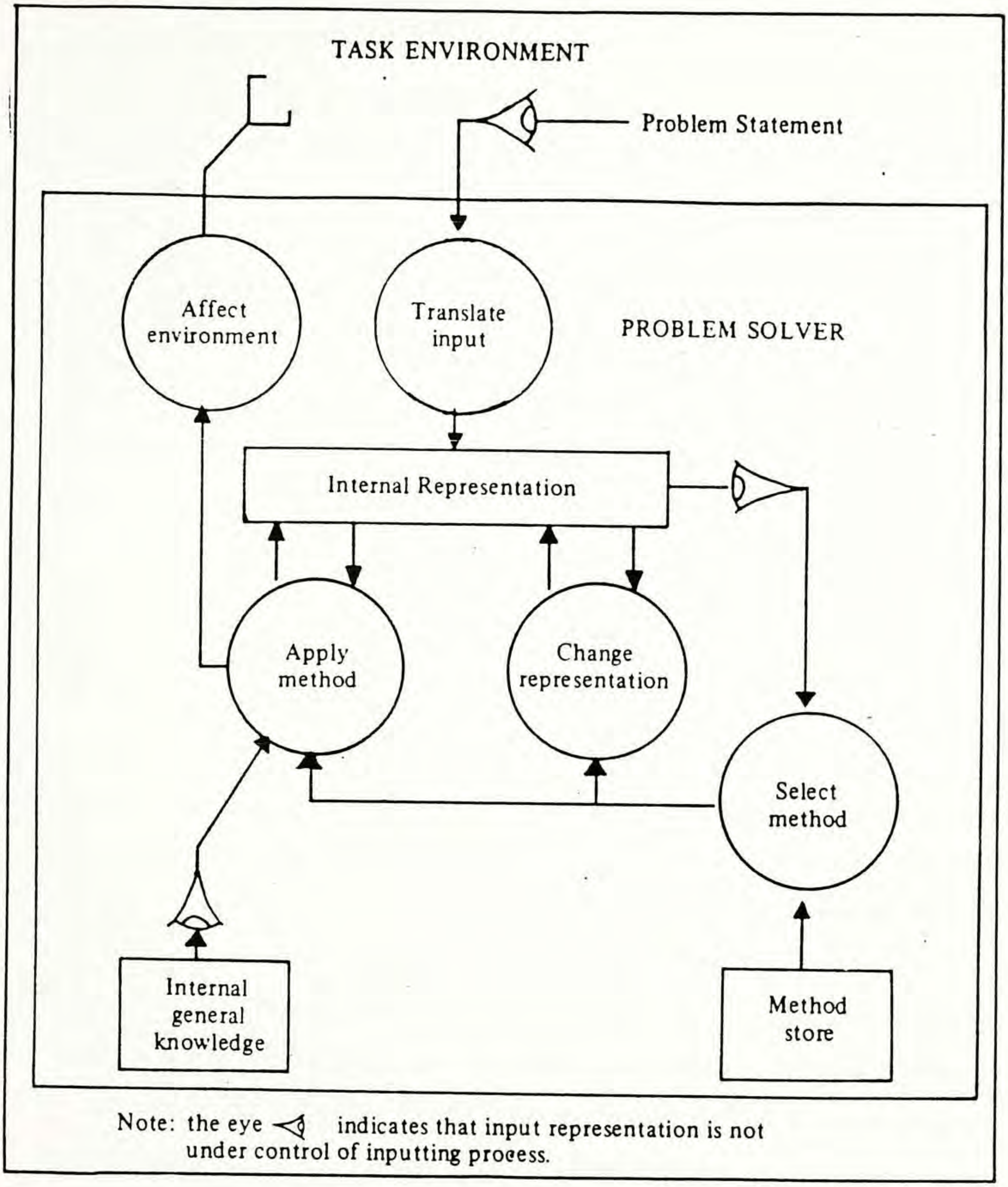

Figure 2.1. General organization of problem solver with reference to the information processing model. (After Newell & Simon, 1972)

to solve the problem may be abandoned. During its operation, a method may produce new problems, that is sub-goals, and the problem solver may elect to attempt one of these. The problem solver may also have the option of setting aside a new subgoal, continuing instead with another branch of the original method.

Simon's Information Processing Theory

Simon's (1978) theory characterized problem solving as an interaction between a task environment, which is a problem, and a problem solver, who is thought of as an information-processing system (Kahney, 1986). Moreover, Sternberg (1985) elaborated the information-processing approach, while Kahney (1986) gave a good summary of Simon's theory. Simon pointed out that in order to solve problems, people must construct a mental representation of the given problem information: initial state, goal, operators and operator restrictions. Simon referred to this mental representation of the problem as the person's problem space. During the course of solving a problem a solver progresses through a sequence of knowledge states. A knowledge state contains the information available to a person at each point in the problem solving process, or which can be made available. Transformation of a knowledge state is accomplished by applying mental operations to change it into another knowledge state.

The Task Environment

A human being behaves in a number of different classes of situations, which we will come to call task environment (Newell & Simon, 1972). The task environment is the problem statement and the context in which the statement is presented, that is, the "objective" statement of the problem as found under particular conditions (Voss, Greene, Post, & Penner, 1983).

The Problem Space

To carry on his problem-solving effects, the problem solver must represent the task environment in memory in some manner. This representation is his problem space (Simon, 1978). Mayer (1983) defined problem space as the problem solver's internal representation of (i) initial state, in which the given or starting conditions are represented; (ii) goal state, in which the final or goal situation is represented; (iii) intermediate problem states, consisting of states that are generated by applying an operator to a state; and, (iv) operators, the moves that are made from one state to the next. Voss and his colleagues (Voss, Greene, Post, & Penner, 1983) clearly pointed out that when presented with a problem, the solver establishes a problem space that consists of information known or potentially available to the solver that may be useful in solving the problem. This information includes first, problem goal and subgoals; second, the possible state of the problem; third, the operator; and finally, the problem space contains the solver's knowledge of constraints under which a problem is to be solved.

The Information-processing System and the Memory Structure

Greeno (1973) has proposed the memory model for problem solving . The three main components in describing problem solving are (i) short-term memory, through which the external description of the problem is input; (ii) long-term memory, that is the semantic and factual memory, which stores past experience with solving problems such as facts, alogorithms, heuristics, related problems, and so on; and (iii) working memory, in which the information from short-term memory and long-term memory interact and the solution route is generated and tested. The information-processing model assumes a short-term or working memory system that is distinct from the long-term memory system. The problem-solving activity is assumed to take place in working memory, and long-term memory is used as a type of resource in the solving process (Voss, Tyler, & Yengo, 1983).

The structural components of the human memory is shown in figure 2.2. A description of the problem, including the initial state, the goal state, and the legal operators, comes into working memory by way of short-term memory as represented by arrows from short-term memory to working memory as shown in figure 2.2; and past experience about how to solve the problem enters working memory from long-term memory, as represented by arrows from long-term memory to working memory. The arrows from working memory to short-term memory and long-term memory to short-term memory suggest that more information from outside world may be required as problem solving processes and the arrow from working memory to long-term memory suggests that the generation of new problem states in working memory may require more old information from past experience (Mayer, 1983). The inputs and outputs of the elementary processes are held in a small short-term memory with a capacity of only a few chunks. The system has access to an essentially unlimited long-term memory, but the time required to store a new chunk in that memory is much longer (Simon, 1978; Anderson, 1985). Working memory is considered to have a limited capacity, which means, in terms of the problem-solving model, that only a few states of the problem can be held in working memory at any one time. The problem solver is thus presumed to move from state to state without much backtracking, primary because of the difficulty of going back to states that are no longer in working memory. However, when a solver reaches a particular state and apparently cannot advance toward the goal from that state, the solver may return to the problem representation and define a new or modified problem space (Voss, Tyler, & Yengo, 1983).

The human information-processing system for problem solving operates almost entirely serially, one process at a time, rather than parallel fashion. Furthermore, the problem solving behavior takes the form of sequential search, making small successive accretions to the store of information about the problem.

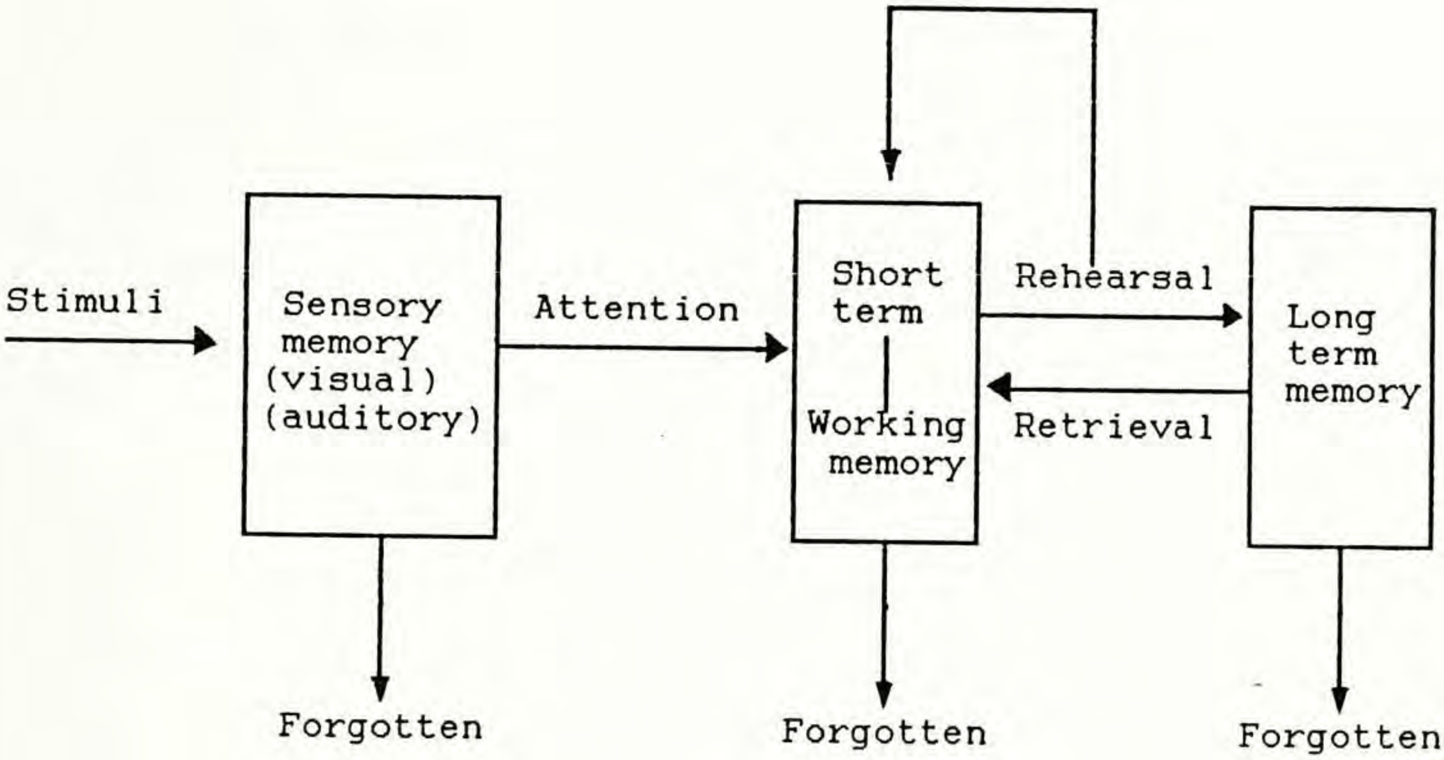

Figure 2.2. A separate-store model of memory (After Houston, 1986)

The Problem-solving Process

Greeno (1973) referred to mathematics problems and suggested that problem solving process might be sub-divided into five sub-processes called stages in solving a problem. First of all, the problem is stated in a form that has to be read by a subject. Secondly, the subject interprets concepts. Thirdly, the subject retrieves information from memory in trying to figure out how the problem can be solved. Fourthly, the subject constructs a solution plan. The subject has to find a set of formulas or other operations that suggest a way of solving for the unknown variable or otherwise developing the solution. Lastly, calculations or other operations have to be carried out.

Gick (1986) indicated that recent information-processing theories of problem solving emphasize two important processes: (a) generation of a problem representation or problem space, that is, the problem solver's view; and (b) a solution process that involves a search through the problem space. Gick (1986) further derived a schematic diagram, as shown in figure 2.3, showing such problem-solving process. During the problem solving process, the solver, first extracts the given and goal information and attempts to understand the problem or to connect the problem to existing knowledge, while constructing a representation of the problem. If schema activation should occur during the construction of a problem representation, then, the solver can proceed directly to the third state of problem solving as shown in figure 2.3. If there is the absence of appropriate schema activation, the problem solver proceeds to the second step and search strategy is invoked. The search strategies include comparison of problem states to the goal state and the use of information-gathering strategies. Additional general problem-solving strategies may be applied later in the solution process.

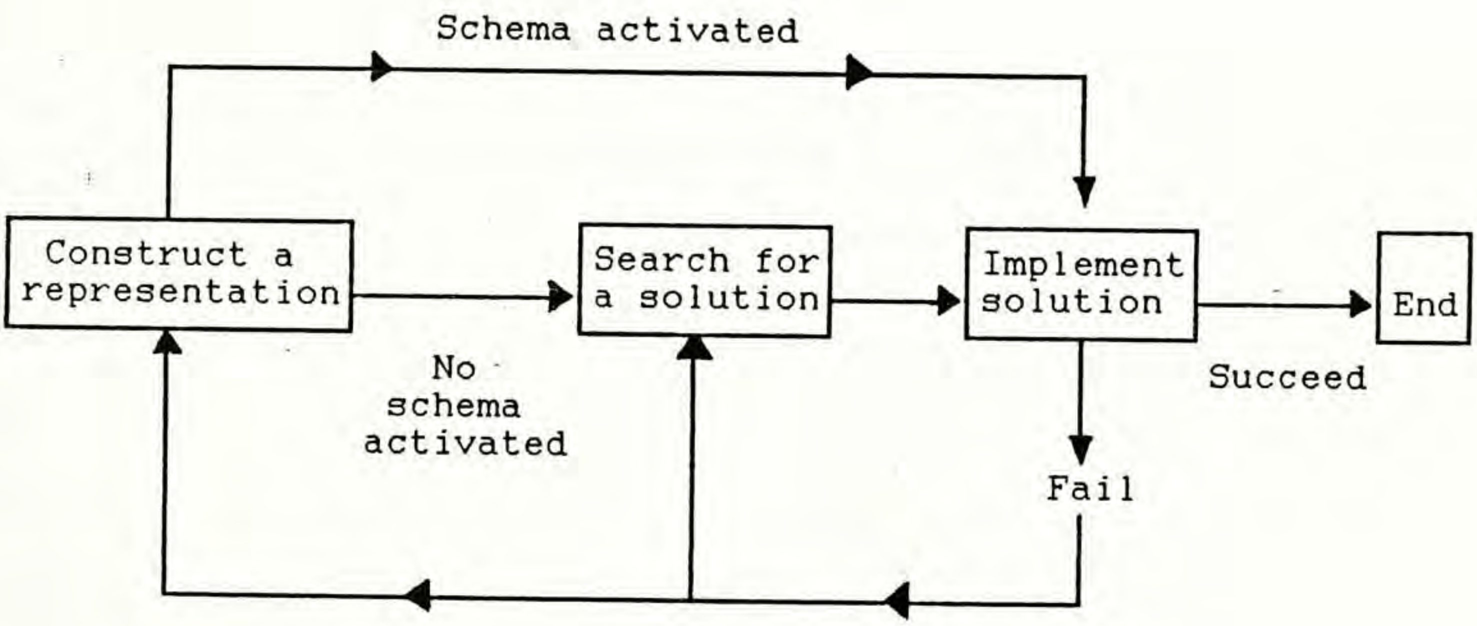

Figure 2.3. Schematic diagram of the problem-solving process (After Gick, 1986)

Anderson's Cognitive Theory
and the Memory Structure

Anderson (1983) presented his latest version of his well-known cognitive theory called "ACT" and argued tellingly that the new "ACT" system provided a basic framework for a unified theory of the human mind.

The system was described by Anderson (1976) as "ACTE". The Anderson's Cognitive Theory (ACT and the revised ACT*) was substantially revised over Anderson's earlier theories and clearly presented in 1983. The general framework of ACT is diagrammatically shown in figure 2.4. An ACT production system consists of three memories: working, declarative, and production. Working memory contains the information that the system can currently access, consisting of information retrieved from long-term declarative memory as well as temporary structures deposited by encoding processes and action of production. However, knowledges are stored in the declarative memory in the form of chunks or cognitive units as they are called in ACT*. In each case a cognitive unit encodes a set of elements in a particular relationship. On the other hand, production memory or the production system is comparable to the schema system. It is the architectures for matching, recognization and evoking.

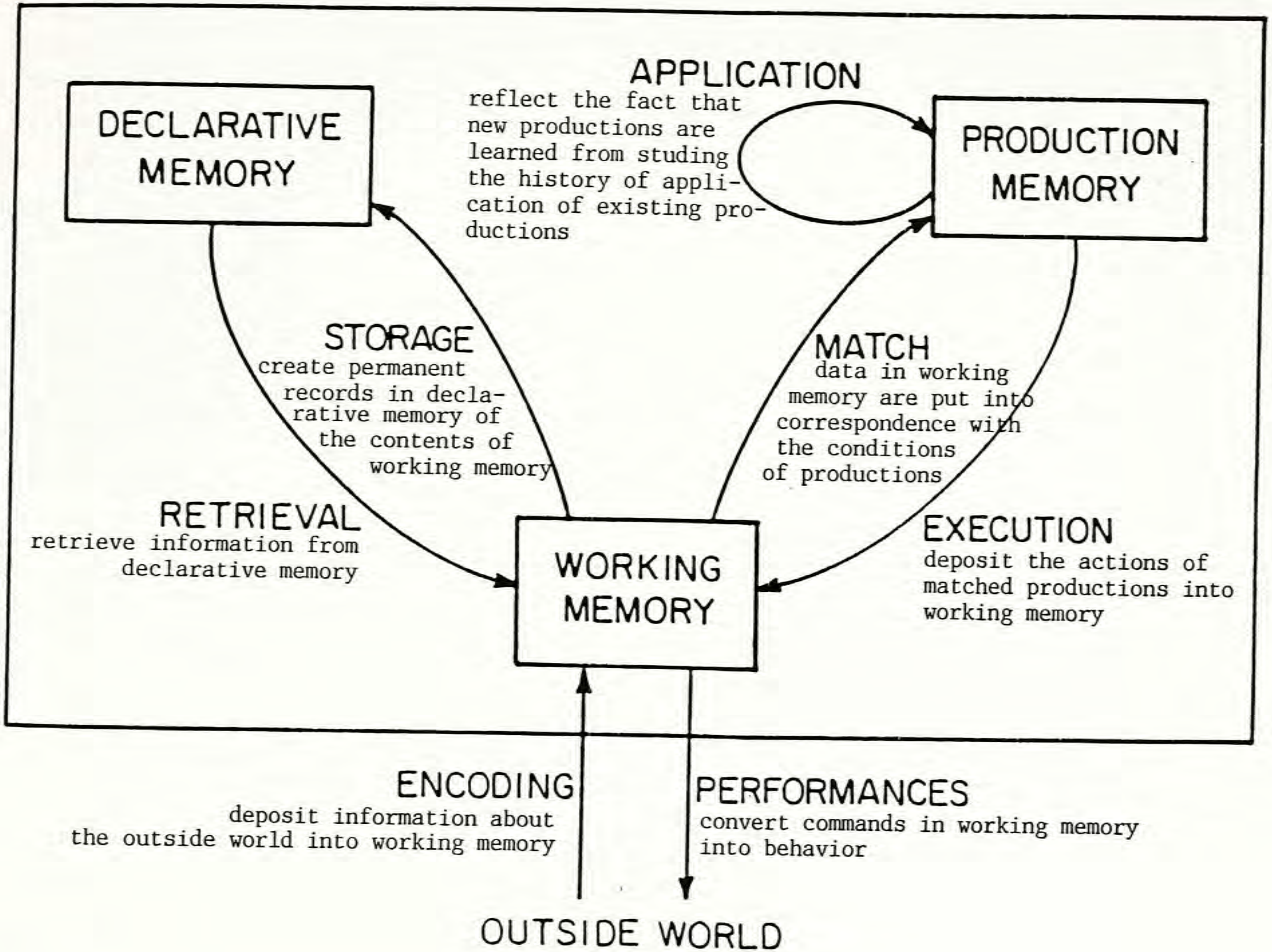

Figure 2.4. A general framework for the Anderson's Cognitive Theory production system, identifying the major structural components and their interlinking processes (after Anderson, 1983)

THE NATURE OF SOCIAL SCIENCE PROBLEMS

A major characteristic of social science problem is the ill-structured nature of the problems. Most cognitive psychologists deal with problems like the "Tower of Hanoi" problem, the "missionary-cannibal river crossing" problem, the physics and mathematics problems, which are well structured, the initial state and the goal of the problem are clearly delineated and the steps required to reach the goal are well defined. However, problems in social sciences are mostly poorly structured.

Reitman (1964) discussed many different kinds of ill-defined problems. He has analyzed four categories of problems according to how well the given and goal states are specified. The four categories are (i) well-defined given state and well-defined goal state; (ii) well-defined given state and poorly defined goal state; (iii) poorly defined given state and well-defined goal state; and, (iv) poorly defined given state and poorly defined goal state. Of these four types, the latter three are categories of ill-structured problems. Nevertheless, Reitman (1965) noted that there emerged a concept of a continuum which ranges from well-defined formal problems on one hand to such ill-defined problems as imposing a fugue on the other. Moreover, Simon (1973) pointed out that the boundary between well structured and ill structured problems is vague, fluid and not susceptible to formalization. An ill structured problem is usually defined as a problem whose structure lacks definition in some respect. A problem is an ill structured problem if it is not a well structured problem. Following Simon's idea, Chi and Glaser (1985) indicated that problems which do not fall into the class of well-defined problems might be considered ill-defined problems. A problem can be qualified as ill-defined or ill-structured if any one of the three components - the initial state, the operators and the goal state - are not well specified. While Reitman (1965) claimed that a problem could be treated as ill-defined when no solution to the problem could be counted on universal acceptance.

Voss and his co-workers (Voss, Greene, Post & Penner, 1983) pointed out two general characteristics of social science problems. Many social science problems involve the existence of an undesirable state of affairs (the problem) that requires improvement (the solution). First of all, social science problems seldom have a single and definite solution about which experts are in complete agreement. Secondly, in most social science problem solving there is a relatively long delay from the time a solution is proposed and accepted to when it is fully implemented.

There is a lack of systematic bases for dealing with ill-structured problems in ways analogous to those made possible with some types of well-structured problem by the various available formalisms (Reitman, 1965). When social science problems, mostly ill-structured problems, are considered specifically within the context of the information-processing model of problem solving Voss and his associates (Voss, Greene, Post, & Penner, 1983) find that first of all, goal of many social science problems is often vaguely stated. Secondly, the distinction of subproblem and constraint in social sciences thus appears to be less definite than in other areas like physical sciences. In social sciences constraints and subproblems are usually not given in the problem statement, and the solver must rely upon his or her knowledge of the field to identify these factors. Thirdly, after proposing a solution, the solver may provide support for the proposed solution or evaluate any of the solution, with one or more constraints serving as the evaluation criterion. Thus, social science problem solving includes argument development which involves "building a case" for a proposed solution. In addition, Voss, Fincher-Kiefer, Greene and Post (1986) pointed out further that differences obtained in physics and social science problem solving reflect not differences related to the subject matter of study, but differences in the extent to which problem solutions have been developed in the domains. Thus, while Larkin (1980, 1981) worked with textbook problems having known solution, Voss and his co-workers studied the social science problems which do not have known and well-accepted solutions. Thus, analysis of the problem-solving activity may differ from mathematical sciences to social sciences as a function of the problem presented, that is, whether the problem has a known solution in the particular domain.

DOMAIN-SPECIFIC KNOWLEDGE IN SOCIAL SCIENCE PROBLEM SOLVING

Importance of Knowledge in Problem Solving

Greeno (1978a, 1978b) emphasized that what a student must know in order to solve problems in a domain was the necessary knowledge represented in the texts and other instructional materials used in the curriculum. He illustrated his idea by means of a research concerned with problem solving in high school geometry. Greeno (1980c) further established two aspects of the importance of knowledge to problem solving. First of all, he pointed out that attention should be paid to the situations in which the performer has relatively specific knowledge that makes problem solving quite easy. Secondly, other situations in which the performer must resort to more general knowledge and procedures to solve a problem should also be noted. Again, he mentioned that these two situations should be a continuum, not a dichotomy setting. In the analysis of mathematics problems, Mayer (1983) sub-divided domain-specific knowledge into five types. The five types are (i) linguistic knowledge, which is the knowledge of language, Chinese, or English or else, such as recognizing words, understanding sentences and questions; (ii) semantic knowledge, which is the knowledge of facts; (iii) schema knowledge, which is the knowledge of problem types; (iv) procedural knowledge, which is the knowledge of how to perform a sequence of operations; and (v) strategic knowledge, that is the technique for how to use the various types of available knowledge in solving a given problem, such as setting subgoals. On the other hand, Green, McCloskey and Caramazza (1985) noted that scientific knowledge should be of two sorts, knowledge of certain facts, principles and laws, and knowledge of procedures for applying the relevant factual knowledge to the problem situation. Moreover, information about procedural knowledge in physics and mathematical sciences has been obtained through a comparison of novices and experts solving problems (Chi, Glaser & Rees, 1982; Larkin, McDermott, Simon & Simon 1980; Tao, 1989; Wong, 1989).

Social science problems differ from mathematics problems. Besides, social science problems differ greatly from the "Tower of Hanoi" problem and the "missionaries-and-cannibals" problem in that the social science problems are domain-specific problems while the latter are general problems. Generally speaking, in the domain-specific problems, knowledge about a given area can facilitate problem solution within that area. The five types of knowledge derived by Mayer (1983), as mentioned in the previous paragraph, are required in social sciences problem-solving. However, the degree of importance and the practice of these five types may vary from mathematics to social sciences. Prior knowledge "transfers" to the current domain-specific problem (Houston, 1986). Modern learning theory recognizes that a person learning facts, concepts, rules and theories has acquired a large collection of knowledge structures (Greeno, 1980c). Research data on problem solving done in knowledge-rich domains show strong interactions between structures of knowledge and cognitive processes

(Chiesi, Spilich & Voss, 1979; Glaser, 1984). Expert performance is characterized by rapid access to an organized body of conceptual and procedural knowledge (Glaser, 1986).

Knowledge and the Theory of Schema

In order to study how structured knowledge facilitates problem solving, theory of schema should be examined beforehand. Gagne (1985) highlighted that a set of schemata should be one of the problem-solving essentials. Schema is defined by Glaser (1986) as a modifiable information structure that represents generic structures of concepts stored in memory. Nevertheless, Mayer (1983) suggested that a general definition of schema should contain the following four points. (i) General - a schema may be used in wide variety of situations as a framework for understanding incoming information. (ii) Knowledge - a schema exists in memory as something that a person knows. (iii) Structure - a schema is organized around some of them. (iv) Comprehension - a schema contains "slots" that are filled in by specific information in the passage. Mayer (1983) further concluded that a schema should be a general knowledge structure used in comprehension, which would serve to select and organize incoming information into an integrated, meaningful framework. Reimann and Chi (1989) summarized that schemata should contain the following four features. (i) Schemata contain variables; a schema of concept has fixed parts, which are assumed always to be true for instances of the concept, and variable parts. (ii) Schemata can embed one within another. (iii) Schemata represent knowledge on all levels of abstraction. (iv) Schemata are active processes, actively trying to evaluate incoming information and ascertaining the degree to which they are relevant to structuring the input.

Glaser (1986) mentioned that schemata represent knowledge that we experience, that is interrelationships between objects, situations and events that occur. In this sense, schemata are prototypes in memory of frequently experienced situations that individuals use to integrate and interpret instances of related knowledge. Schemata are closely related to chunks. Schema theory assumes that there are memory structures in memory for recurrent situations that are experienced, and that a major function of schemata is to construct interpretations of new situation (Chi & Glaser, 1985). The objects of a schema may be thought of as slots into which incoming information can fit. An active schema can guide you to seek information to fill its remaining slots.

Gagne (1987) consolidated the idea of schema and defined schema as a memory structure representing a general concept and its framework of associated concepts. Such concept provides for linking of particular details at locations that are established by experience with the general concept. Reimann and Chi (1989) summarized the schema theory that it could explain the following phenomena relating to problem solving and cognitive activities: (i) rapid categorization (via pattern matching); (ii) inference or elaboration activities (relating to filling the schema slots with default values); (iii) top-down and forward-working processing in solving problems; and (iv) hierarchically organized knowledge (via embedding of schemata).

Marshall (1988) outlined a model of human memory based on schema and knowledge structures. Knowledge structure is general organization of long-term memory into networks. Individual pieces of knowledge are viewed as nodes in the networks. These nodes may be linked together or may exist as isolates. Retrieval of information from memory depends upon where the information resides within the network. Experts appear to have rich, highly interconnected networks. Novices are more likely to have fragmented, partially linked networks, possibly with inappropriate links between nodes. Activation of one node causes the activation of the other surrounding nodes that are linked to the target. Links between nodes vary in intensity. The degree to which activation spreads among nodes will be influenced by the strength of the associations that connect the nodes. Through learning, individual nodes are added to long-term memory and groups of them become connected. The primary mechanism under which these connections are made and by which meaningful learning occurs is the schema. A schema is a knowledge structure that allows the individual to recognize aspects of his or her environment and to operate on them, either abstractly or concretely. Marshall (1988) further developed a model of schema built upon four basic components -- first, the component of general representation of the situation; second, the recognization of presence or absence of constraints; third, the planning mechanisms relating to implementing the schema, that is, the goal-forming procedures; fourth, the actions and procedures in implementation of the schema. Each of these components would activate the others. The depth to which any component might be activated and accessed by the individual depends upon the complexity of the problem. Minor problems require little cognitive processing, while difficult ones might involve access to many different schema.

Relating to problem solving, Chi and Glaser (1985) explained that once a schema would be trigger, a solver could decide on the solution if the schema had contained the necessary information. If it is a specific and appropriate schema, it might contain precisely the right procedures, enabling the solver to proceed easily and rapidly. If an inappropriate schema is triggered, or if information cannot be found from the schema, the solver will not make any progress at all. It is the organization and structure provided by schemata that allow relevant knowledge to be found in memory. Thus either lack of knowledge or lack of access to knowledge because of inadequate structure may be the reason for failure to solve a problem. Chi and Glaser (1985) summarized that studies on the solution of problems where a great deal of domain knowledge is involved indicate clearly that a very relevant part of success in problem solving is the ability to access a large body of domain knowledge.

Again, research carried out by Glaser (1984) suggested that experts' knowledge is organized around principles and abstractions that subsume these objects. The knowledge of experts includes also knowledge about the application of what they know. For expert, these aspects of knowledge comprise tightly connected schema. The novice's schema may contain sufficient information about a problem situation but lack knowledge of related principles and their application. The problem-solving difficulty of novices can be attributed largely to the inadequacies of their knowledge bases and not to limitations in their processing capabilities such as the inability to use problem-solving heuristics.

Back to social science problems, Voss, Tyler and Yengo (1983) and Voss, Greene, Post and Penner (1983) had studied the expert and novice problem solving in the "Soviet agriculture problem". Protocols were obtained from the social science undergraduates with and without knowledge in U.S.S.R., and, non-social science undergraduates. Results showed that experts used their extensive data base to examine and evaluate proposed solutions and isolate subproblems that may arise in the implementation of the solution. Social science faculty members whose field of expertise was not U.S.S.R. tended to use strategies similar to those of the experts but generally were unable to apply domain-related strategies or examine solutions effectively because of apparently insufficient knowledge bases, while the novices' protocols - the protocols of science undergraduates without knowledge of U.S.S.R. - lack domain-related strategies and lack knowledge base. Such study confirms the role of knowledge in social science problem solving.

SOCIAL SCIENCE PROBLEM SOLVING STRATEGIES

Cognitive strategies enable a person to select appropriate information and skills and to decide when and how to apply them in attempting to solve the problem (Gagne, 1985). Matlin (1983) outlined several strategies for solving ill-structured problems. Similarly, Chi and Glaser (1985) proposed similar strategies for ill-defined problems. These strategies may be applied to the solving of social science problems. One strategy which is familiar to those social scientists is to break the problem into several subproblems. Work on each subproblem independently, and then combine them and resolve any incompatibilities. All the subjects, from expert to novice, use this strategy. The differences, however, are that the experts tend to create a few very general subproblems that might encompass several related causes, whereas the novices relate solutions very directly to individual causes (Matlin, 1983; Chi & Glaser, 1985; Glaser, 1986). A second strategy in solving ill-defined problems is to add more structure to the situation. One problem with an ill-structured problem is that there are so few constraints or limitations in the task. In order to reach a solution, we must somehow restrict the possibilities. Chi and Glaser (1985) noted it as a creative act or insight. A third strategy for ill-structured problems is to start work on the problem even if you do not yet understand it completely. A fourth strategy is to stop when you have a solution, even if it may not be the best possible solution. In other words, the goal state is arbitrary, so we can be arbitrary about deciding that task is finished.

In dealing with the well-structured problem, subjects may use techniques of heuristics like mean-ends analysis, subgoaling, and generate-and-test. Even in dealing with ill-defined problems, solvers use heuristics like those in well-defined problems (Chi & Glaser, 1985; Voss, Greene, Post & Penner, 1983; Voss, Tyler & Yengo, 1983). Considering experts and novices, the knowledge of experts, organized into structures such as schemata, allows for the effective use of sophisticated strategies that are used infrequently or poorly by novices (Gick, 1986; Gomez, 1981; Kolodberg, 1983). Furthermore, the very nature of ill-defined problems means that solvers define the problems better than for the problems themselves (Chi & Glaser, 1985).

Besides, Voss, Fincher-Kiefer, Greene and Post (1986) noted the significance of domain-specific strategies in social science problem solving. Referring to the Soviet agricultural problem, experts used some domain-specific strategies, such as examining the problem history, evidently to isolate the factors primarily responsible for the problem. Experts also used their extensive data base to examine and evaluate proposed solutions and isolate subproblems that may arise in the implementation of the solution. On the other hand, novices showed a lack of domain-related strategy as well as an underdeveloped knowledge base.

CHAPTER 3

THE SOCIAL SCIENCE PROBLEM-SOLVING MODEL

EARLY DEVELOPMENT OF THE SOCIAL SCIENCE PROBLEM-SOLVING MODEL

As mentioned in the previous part of this paper, relatively little attention was paid to the development of a theoretical framework for the study of the processes of problem solving in social sciences. Voss and his associates, who are pioneers in developing social science problem solving theory, have proposed an embryonic model for social science problems. Voss, Tyler and Yengo (1983) have incorporated Toulmin's jurisprudence model of argument (Toulmin, 1958; Toulmin, Ricke, and Janik, 1979) into the information processing framework (Newell and Simon, 1972; Simon, 1978) to social science problem solving.

Toulmin's model, which is a philosophical one, describes the components of a single argument. Toulmin's model was borrowed by Voss and his co-workers on the fact that social science problem solving involves the development of a series of arguments. The Toulmin's model is claimed to be helpful because it provides a description as well as measures of the argument structure, enables quantification, and determines the nature of information. Despite the usefulness just mentioned, Voss, Tyler and Yengo (1983) claimed that there were certain drawbacks. The most serious of which was the lack of a problem-solving control structure. They realized the necessity of developing another model with refined description of the social science problem-solving process.

THE PROBLEM-SOLVING-REASONING MODEL

The problem-solving-reasoning model proposed by Voss and his associates (Voss, Greene, Post & Penner, 1983) took the deficiency of Toulmin's jurisprudence model into account by assuming two structures, a problem-solving structure and a reasoning structure, each with its own set of operators. This latter developed model is more useful and suitable than the early attempt. Details of the model are presented in the following paragraphs.

Based on the general information processing model of problem solving (Newell & Simon, 1972; Simon, 1978), as in the early attempt, Voss and his colleagues (Voss, Green, Post & Penner 1983; Penner & Voss, 1983) proposed a model of problem solving in social sciences. Within the framework of Voss and his colleagues, social sciences problem-solving is an integration of two processes - problem-solving process and verbal reasoning. Voss-

Greene, Post and Penner (1983) indicated that Goal structure controlled the problem-solving process; while Reasoning Structure operators were referred to as the verbal reasoning. Goal (G) structure consists of operators that act upon the individual knowledge base and generate the problem solution. The G structure operators - stating constraint (GCON), stating subproblem (GSUB), and stating solution (GSOL), constitute the "hard core" operators, which in some form or another are found in most problem solving activity and are self-explanatory. The supportive G operators - interpreting problem statement (GIPS), providing support (GSUP), evaluation (GEVA), and summary (GSUM) are used in conjunction with the Reasoning Structure operators. Detailed descriptions of these G operators are listed in Table 3.1.

Moreover, the problem-solving control structure may be expressed in a way as shown in figure 3.1. Initially, the problem is stated. Then, the individual develops a problem representation which, in a sense, is the solver's interpretation of the problem statement. General problem solving may then be viewed as stepwise movement toward a goal. Constraints are identified. Underlying factors, that is factors affecting the decision, are recognized. This is found important and essential in social sciences problem solving. Most of the social sciences problems, ranging from agricultural decision to industrialization, urbanization, to political problems, may be diagnosed by a lot of underlying factors. The problem is then decomposed into a number of subproblems, and solutions are sought for the subproblems. Finally, through the solving of subproblems, the solver offers a solution to the problem. And, support or evaluation may also be given for such proposed solution.

Reasoning structure controls the verbal reasoning. The application of the R structure begins with an argument made by the solver. Subsequently, a combination of the remaining operators is applied in the argument development. The R structure operators are applied in conjunction with the supportive goal structure operators. Detailed description of R structure operators are shown in Table 3.2.

With reference to the concepts of knowledge-and-schema mentioned in the previous chapter, this problem-solving-reasoning model may be interpreted as follows. Domain-specific knowledge, the knowledge of domain-related strategies as well as procedural knowledge can be viewed as nodes in the networks of long-term memory. The linkage of these nodes varies from experts to novices. Piece of knowledge linked to the densely interconnected networks are more accessible than those unlinked ones. Thus, faced with a social science problem, schemata are the means by which responses are constructed by the individual. Following the proposition of Marshall (1988), interpretation of problem statement as well as stating of constraints are components in the schema model. Initial access to the schema could be started from any one of these components, then such commencement might be resulted in activation of the entire set of nodes that define the schema. Whenever the procedural knowledge is properly retrieved, individual may follow the stepwise goal approaching movement in the problem solving process. Whenever the appropriate domain-related strategies are retrieved, individual may approach the problem by unraveling the underlying factors. However, the number of appropriate underlying factors identified by an individual depends on the amount of pieces of domain-specific knowledge as well as the state of the linkage of these pieces of knowledge. Again, the number of supporting argument provided and the reasoning structures developed rely on the condition of retrieval of the pieces of domain-specific knowledge.

Eventually, this problem-solving-reasoning model will be used as a framework and reference for the future and further analysis in this study.

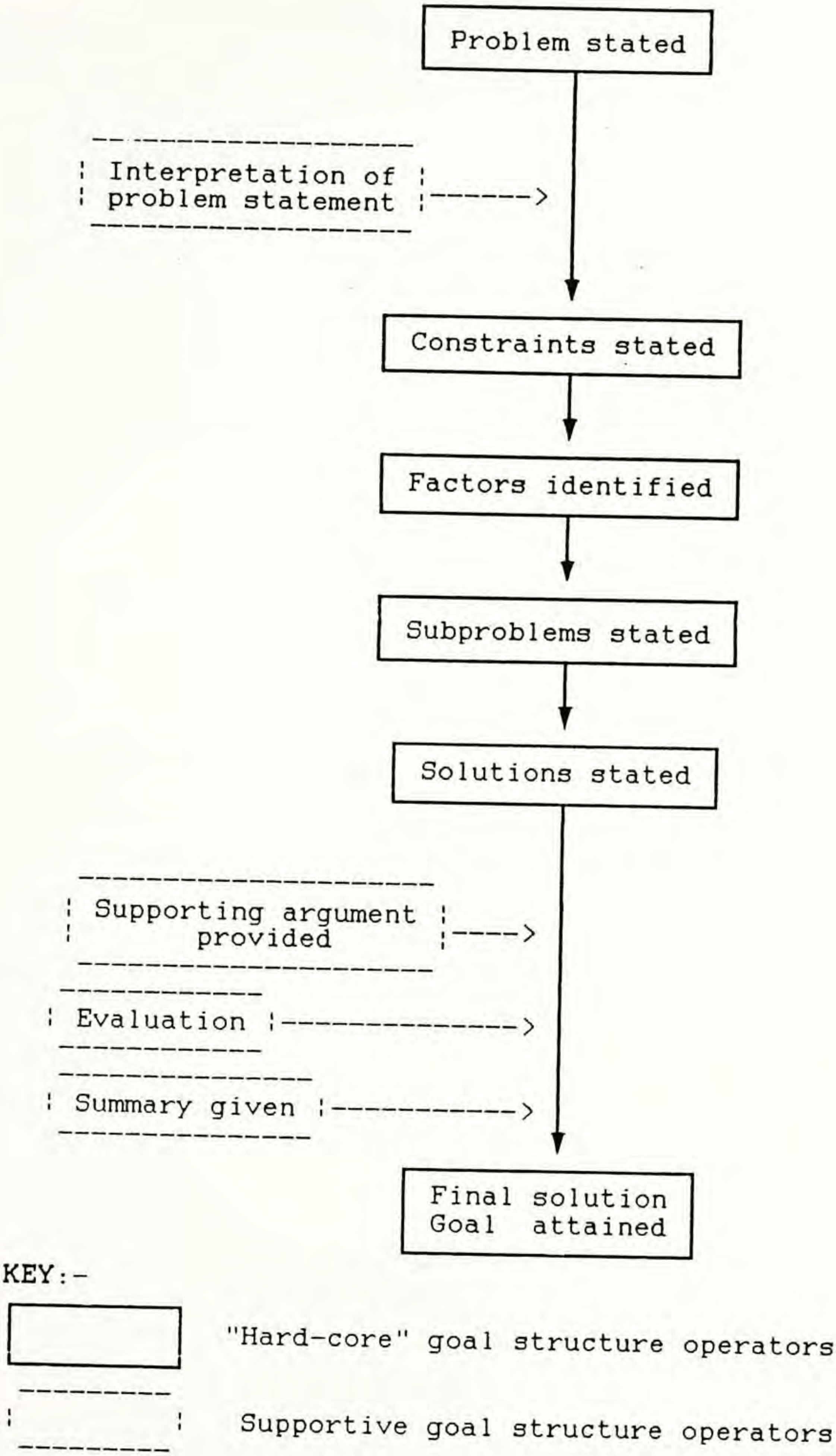

Figure 3.1: The problem-solving control structure model.

Table 3.1: The G operators

CODE	OPERATOR	EXPLANATION
(a) "Hard-core" operators		
GCON	State constraint	It is the factor that is assumed to be invariant over the course of solving a particular problem. It is applied when a solver explicitly or implicitly indicates a problem constraint.
GSUB	State subproblem	It is a problem that are subordinate to a more general problem. It is applied when a solver indicates that a particular factor is being used as a subproblem.
GSOL	State solution	It is applied when the solver states a solution, either to the given problem or to a subproblem, explicitly or implicitly expressed.
(b) Supportive operators		
GIPS	Interpret problem statement	It is applied when the solver considers how problem is to be interpreted.
GSUP	Provide support	It is applied when the solver is using some type of argument to support the existence of a subproblem or constraint.
GEVA	Evaluate	It is applied when (i) the solver develops an argument that supports or rejects a solution, and (ii) when the solver evaluates a solution in relation to a particular constraint. Thus, GSUP is supportive, but GEVA is not.
GSUM	Summarize	It is applied when the solver presents a summary of a relatively large portion of the protocol.

Table 3.2: The R structure operators

CODE	OPERATOR	EXPLANATION
RARG	State argument	It is applied when the solver begins an argument.
RSAS	State assertion	It is applied when the solver refers to a constraint, subproblem or solution, but the factors referred to are not in the goal structure of the solution process.
RFAC	State fact	It is applied when the solver supports another statement via the statement of a fact.
RPSC	Present specific case	It is applied when a specific case or example is used to demonstrate the contents case of a previous statement.
RREA	State reason	It is applied when the solver states a reason for a previous statement.
ROUT	State outcome	It is applied when the solver states an outcome of a previous statement.
RCOM	Compare and/or contrast	It is applied when the solver compares a previous statement with some other entity related to the statement.
RELA	Elaborate and/or clarify	It is applied when the solver attempts to elaborate or clarify a previous statement while essentially not adding anything new.
RCON	State conclusion	It is applied when a concluding statement is provided after a series of previous statements.
RQUA	State qualifier	It is applied when a statement restricts the range of application of the previous statement.

CHAPTER 4

RESEARCH DESIGN

STATEMENT OF HYPOTHESES

This study examined the hypothesis that Form 5 students with high level of knowledge on industrial location would perform better than Form 5 students with low level of knowledge on industrial location in problem solving processes. A number of researchers had conducted studies on expert-novice differences in problem solving in physics (Chi, Feltovich & Glaser, 1981; Larkin, 1983), in chemistry (Heyworth, 1989) and in mathematics (Wong, 1989). This inquiry focused on high-low domain-specific knowledge differences in solving industrial location problems in social science. Again, students of high general learning ability were expected to perform better than students of low general learning ability. General learning ability was employed as a categorizing variable in the hypotheses to be tested. Problem solving performance was expressed in terms of the constraints identified, the sub-problems decomposed, the supportive operators used and the reasoning structures employed in the protocols.

The following null hypotheses were formulated. Moreover, null hypotheses 1 to 10 were tested statistically, while null hypotheses 11 to 12 were tested by means of qualitative analysis.

<u>Hypothesis 1</u>

There is no statistical significant difference between the subjects with high and low knowledge bases with regard to the different ability of subjects in the number of constraints correctly identified in the process of solving a high difficulty level industrial location problem.

<u>Hypothesis 2</u>

There is no statistical significant difference between the subjects with high and low knowledge bases with regard to the different ability of subjects in the number of sub-problems decomposed in the process of solving a high difficulty level industrial location problem.

<u>Hypothesis 3</u>

There is no statistical significant difference between the subjects with high and low knowledge bases with regard to the different ability of subjects in the number of supportive operators used in the process of solving a high difficulty level industrial location problem.

Hypothesis 4

There is no statistical significant difference between the subjects with high and low knowledge bases with regard to the different ability of subjects in the number of reasoning structures used in the process of solving a high difficulty level industrial location problem.

Hypothesis 5

There is no significant interaction between the knowledge bases of subjects and the ability of subjects in the number of constraints correctly identified; number of sub-problems decomposed; the number of supportive operators used; and the number of reasoning arguments used in the process of solving a high difficulty level industrial location problem.

Hypothesis 6

There is no statistical significant difference between the subjects with high and low knowledge bases with regard to the different ability of subjects in the number of constraints correctly identified in the process of solving a low difficulty level industrial location problem.

Hypothesis 7

There is no statistical significant difference between the subjects with high and low knowledge bases with regard to the different ability of subjects in the number of sub-problems decomposed in the process of solving a low difficulty level industrial location problem.

Hypothesis 8

There is no statistical significant difference between the subjects with high and low knowledge bases with regard to the different ability of subjects in the number of supportive operators used in the process of solving a low difficulty level industrial location problem.

Hypothesis 9

There is no statistical significant difference between the subjects with high and low knowledge bases with regard to the different ability of subjects in the number of reasoning structures used in the process of solving a low difficulty level industrial location problem.

Hypothesis 10

There is no significant interaction effect between the knowledge bases of subjects and the ability of subjects in the number of constraints correctly identified; number of sub-problems decomposed; the number of supportive arguments used; and, the number of reasoning arguments used in the process of solving a low difficulty level industrial location problem.

Hypothesis 11

There is no qualitative difference between the subjects with high and low knowledge bases with regard to the difference ability of subjects in (i) problem representation; (ii) sub-problem decomposition; (iii) supportive argumentation; and, (iv) the type of strategies used in the problem-solving processes of solving a high difficulty level industrial location problem.

Hypothesis 12

There is no qualitative difference between the subjects with high and low knowledge bases with regard to the difference ability of subjects in (i) problem representation; (ii) sub-problem decomposition; (iii) supportive argumentation; and, (iv) the type of strategies used in the problem-solving processes of solving a low difficulty level industrial location problem.

OPERATIONAL DEFINITIONS OF VARIABLES

The dependent and independent variables employed in this study were operationally defined as follows.

Knowledge bases

Performance in the Knowledge Test given to the subjects determined the level of knowledge base of the subjects. Those who scored 70% or over in the Knowledge Test were classified as high/with knowledge base, while those who scored under 50% were classified as low/without knowledge base. Only those Form 5 students scored over 70% and under 50% were chosen as subjects in this study. Since questions in the Knowledge Test were set with reference to the factual knowledge about industrial location, knowledge base was regard as "semantic knowledge" (Mayer, 1983) of the specific domain.

Ability

Ability was treated as a moderator variable, more precisely, categorizing variable, in the study. Probably, general learning ability may affect the relationship between knowledge, the independent variable, and problem solving performance, the dependent variable.

Husen and Postlethwaite (1985) defined ability as an individual's potential for acquiring new knowledge or skill. Klausmeier and Goodwin (1975) identified five attributes of abilities. Firstly, an ability is a product of maturation and learning. Secondly, an ability developed during the formative years persists into adulthood. Thirdly, the present abilities of the individual influence the rate at which he learns related new tasks. Fourthly, one ability may underlie performance on more specific tasks than another. Fifthly, an ability is more fundamental than a skill. Relating these attributes to problem solving, it can be understood that ability may have effects on problem-solving performance. Hence, general learning ability will be adopted as categorizing variable.

The relationship between general learning ability and problem solving performance has been studied in different disciplines. Johnson, Skon and Johnson (1980) stratified 45 first-grade children on the basis of general learning ability in the study of the effects of interpersonal cooperation, competition, and individualistic effects on children's problem-solving performance. In such study, students were stratified into high, medium, and low students, with an equal percentage, in reading and mathematical ability. Schonberger (1981) examined gender differences with respect to mathematical problem-solving ability and academic ability. It was founded that higher level of academic reasoning ability tended to produce higher results in mathematical problem-solving among males. Gattiker (1988) studied the effects of academic ability on problem-solving performance in computer skill. Multiple regression was used to determine the significance of factors and the magnitude of effect on the dependent variable in conjunction with other variables including academic ability as determined by the student's grade point average.

In this study, subjects were categorized into high, medium and low general learning ability with respect to their overall academic performance in their schools, the academic standard of the intakes of the school as assessed by the Education Department, and the performance in Certificate of Education Examination of the schools. Details of the grouping of subjects are explained in the following section named "Subjects".

Difficulties of problem

Problems of industrial location were employed in the research. There were two problems of different levels of difficulty. The problem named "Relocating a ball pen factory" was of high level of difficulty, while the problem called "Locating an oil refinery" was of low level of difficulty. Level of difficulty was used in the sense that the the former problem was a less structured problem with debatable options of solution, and embedded with a lot of domain-specific concepts like "labor-intensive" and "government influence". The latter problem was a more structured problem, employing elementary concepts in industrial location.

Factors and sub-problems in the problem-solving processes

There are the appropriate and relevant factors affecting the location of that particular plant of the problem. Irrelevant factors identified may lead to inappropriate solution and detour in the processes of arriving at the solution in the problem-solving processes. Hence, sub-problem may be defined as a problem which is subordinate to a more general problem. It is applied when a solver indicates that a particular factor is being used as a sub-problem.

Supportive operators

They are supportive arguments of some types, in supporting the existence of a sub-problem or constraint in the problem solving processes. The operators include interpreting problem statements (GIPS), supportive statements (GSUP), evaluation (GEVA), and summary (GSUM) statements as defined by Voss, Greene, Post and Penner (1983). Details of these operators are listed in the previous chapter.

Reasoning structures

The definitions of Reasoning Structures proposed by Voss, Greene, Post and Penner (1983) were employed in the variable "reasoning structure" in this study. Again, details of these operators are listed in the previous chapter.

Problem-solving strategy

Problem-solving strategies are any methods or algorithms involved in the problem-solving process. They are the cognitive strategies that make possible the use of the intellectual skills. The social science problem-solving strategy may include the procedures of identification of underlying factors, formation of subproblems and so on, or those strategy which are used in physical science problem-solving, like mean-ends analysis, working backwards, simplification, random search and trial-and-error (Halpern, 1984).

Problem representation

Problem representation is the solver's interpretation of the problem statement (Voss, Greene, Post & Penner, 1983). This is the task situation as perceived by the subject and consists of relationships between the elements in the problem.

SUBJECTS

A total of 30 Form 5 students from two subsidized schools served as subjects. One of the schools, hereafter called school A, is located at Shatin New Town, while the other one, hereafter called school B, is located at Kwun Tong, Kowloon. Both the two schools are Anglo-Chinese schools, and they are both grammar schools as well. The catchment areas of the two schools were public housing estates. The uniform housing style of the public housing scheme in Hong Kong provides a population of broadly similar socio-economic background. Hence, subjects from both schools could be considered as coming from similar socio-economic background.

However, the two schools have the intake of students of different standard. The Education Department of Hong Kong classifies Primary 6 students into five bands of different academic performance, with band 1 the best while band 5 the poorest. The students admitted to Form 1 in school A are mainly band 1 and band 2 students for the past seven years. On the other hand, the students admitted to Form 1 in school B are mainly band 3, band 4 and band 5 students.

Furthermore, there is a marked difference in the academic performance of the Form 5 graduates in the two schools. The passing percentage in Certificate of Education Examination of school A has been over 85% for the past five years. Nevertheless, the passing percentage in the Certificate of Education Examination of school B has been below 45% for the past five years.

Hence, subjects from school A were classified as subjects of high general learning ability, while subjects from school B were of low general learning ability. These 30 subjects were classified into six categories. Details of these six groups are listed below.

<u>Group 1: High knowledge base and high ability</u>

Subjects were arts students in school A undertaking Geography and/or Economics course with good results in the Knowledge Test and ranked one of the first 20 positions in their class in the first term examination in the school in the academic year 1989-1990. Also, the subjects were band 1 students at the time of admitting to their Form 1 studies.

<u>Group 2: Low knowledge base and high ability</u>

Subjects were science students in school A undertaking neither Geography nor Economics course with poor results in the Knowledge test and ranked one of the first 20 positions in their class in the first term examination in the school in the academic year 1989-1990. Also, the subjects were band 1 students at the time of admitting to their Form 1 studies.

Group 3: High knowledge base and medium ability

Subjects were arts students in school A undertaking Geography and/or Economics course with good results in the Knowledge Test and ranking inferior position (one of the bottom 20 positions) in their class in the first term examination in the school in the academic year 1989-1990. Also, the subjects were band 2 students at the time of admitting to their Form 1 studies. In other words, regarding to the banding system of academic achievement, the general learning ability of subjects in this group was lower than that of the "high ability" subjects, but higher than that of the "low ability" subjects.

Group 4: Low knowledge base and medium ability

Subjects were science students in school A undertaking neither Geography nor Economics course with poor results in the Knowledge Test and ranking inferior positions (one of the bottom 20) in their class in the first term examination in the school in the academic year 1989-1990. Also, the subjects were band 2 students at the time of admitting to their Form 1 studies. Similar to Group 4, regarding to the banding system of academic achievement, the general learning ability of subjects in this group was lower than that of the "high ability" subjects, but higher than that of the "low ability" students.

Group 5: High knowledge base and low ability

Subjects were arts students in school B undertaking Geography and/or Economics course with good results in the Knowledge Test and ranked one of the bottom 20 positions in their class in the first term examination in the school in the academic year 1989-1990. Also, the subjects were band 4 and 5 students at the time of admitting to their Form 1 studies.

Group 6: Low knowledge base and low ability

Subjects were science students in school B undertaking neither Geography nor Economics course with poor results in the Knowledge Test and ranked one of the bottom 20 positions in their class in the first term examination in the school in the academic year 1989-1990. Also, the subjects were band 4 and band 5 students at the time of admitting to their Form 1 studies.

Distribution of subjects

The categories and number of subjects are listed in the table 4.1.

Table 4.1. Distribution of subjects.

	High knowledge base	Low knowledge base	Total
High ability	5	5	10
Medium ability	5	5	10
Low ability	5	5	10
Total	15	15	30

INSTRUMENTS

Instruments consisted of (i) knowledge test, (ii) industrial location problem of high difficulty level, and (iii) industrial location problem of low level of difficulty. All the three instruments were presented in English with Chinese translation for key terms and concepts. Since the subjects were Form 5 students from two Anglo-chinese schools, using English as the medium of instruction in their Geography lessons, taking English version papers in Certificate of Education Examination as well, so the instruments presenting in English would cope with their mode of study. Furthermore, simple English was used in the instruments. Subjects might write in either English or Chinese in answering questions of industrial location problem. Hence, language would neither form barrier in understanding and interpreting the problems nor act as an obstacle in protocol formation.

Knowledge Test

It was a test consisted of 25 multiple-choice questions. There were straight forward and simple memory recall questions asking subjects the factors which affect industries. All questions fell within the "knowledge" level in the taxonomy of cognitive domain defined by Bloom (1956). None of the questions required "application", "analysis", "translation", "synthesis" or "evaluation" which are in the higher levels in Bloom's taxonomy.

Moreover, the aim of the test was to see whether the knowledge of industrial location was attained by the subjects. The test is shown in Appendix 1.

A pilot study of the Knowledge Test was conducted. Forty nine students from an Anglo-Chinese secondary school were asked to complete the Knowledge Test. These 49 students consisted of Form 5 non-repeaters of arts stream with mixed academic performance, Form 5 repeaters of arts stream, Form 6 students undertaking Advanced Level Geography and/or Economics, and, Form 6 students neither undertaking Advanced Level Geography nor Advanced Level Economics in their studies.

The reliability of the Knowledge Test in the pilot study was calculated. The reliability coefficient, using Kuder-Richardson Formula 21, was found to be .82. Such a value was high enough to claim that the Knowledge Test should be a reliable one.

Item analysis of the pilot test was carried out. Index of difficulty and index of discrimination for each item were calculated. The indices of the 25 items of the Knowledge Test are listed in Table 4.2.

Table 4.2. Item analysis of the Knowledge Test

Question No.	Index of Difficulty (%)	Index of Discrimination
1	76.92	0.46
2	61.54	0.46
3	76.92	0.46
4	69.23	0.46
5	69.23	0.62
6	65.39	0.69
7	61.54	0.62
8	73.08	0.53
9	34.62	0.23
10	61.45	0.31
11	80.77	0.39
12	80.77	0.23
13	50.00	0.39
14	50.00	0.39
15	69.23	0.46
16	42.31	0.69
17	30.77	0.46
18	57.69	0.23
19	42.31	0.69
20	69.23	0.62
21	46.15	0.92
22	65.39	0.69
23	69.23	0.62
24	65.39	0.62
25	50.00	0.53

Industrial Location Problem of High Level of Difficulty

The test was named "Locating a ball pen factory". The material for testing was adopted from Goodwin's (1982) simulation problem. The simulation was originally devised for students in further education colleges and Advanced Level studies in United Kingdom. The area for the simulation was an area in Northern England. The original simulation was rewritten in simple English, measurements converted into metric units which are more familiar to students in Hong Kong. All English place names were turned to fictitious names. Subjects were asked to relocate a plant in a fictitious area. They were required to choose a suitable place out of the three choices. The problem was of high level of difficulty in the sense that it was typically an ill-structured problem. Details of the problem is shown in Appendix 2. Of the three choices in the problem, "site A" cannot be adapted as solution to the problem. However, we have no clear way of judging whether which one of the other two choices is correct. Referring to Appendix 2, site A may not be the appropriate answer, nevertheless, sites B and C may be treated as possible solutions to the relocation problem.

Industrial location problem of low level of difficulty

The problem was named "Locating an oil refinery". The problem was adopted from the work of Ayers and his colleagues (1982). It was originally a discussion exercise concerning the oil and gas development in Britain with special reference to the North

Sea Oil Field and oil refineries for lower form secondary pupils in United Kingdom. The passage and discussion questions were rewritten to make it into a problem solving exercise. As in the previous problem, all English place names were turned to fictitious names. Since more detailed information was given in this problem and the solution to the problem stands out more clearly. It is more clearly structured, and, this problem was treated as a problem of low level of difficulty. Details of the problem is shown in Appendix 3.

<u>Pilot study of the Industrial Location Problems</u>

Three social science university graduates with Diploma in Education, two majoring in Geography and one majoring in Economics, were asked to solve the two problems of industrial location. The problem solving processes were recorded in written work and supplemented by interviews. These works were reorganized according to the framework proposed by Voss, Greene, Post and Penner (1983) into a tree-like diagram showing the factors, sub-problems, reasons and other operators. Figure 4.1 shows such tree-like diagram. Such re-organization was acted as framework and guide for interview relating to subjects in the research.

In addition, two subjects from secondary schools were chosen for the pilot study of the Industrial Location Problems. One of the subjects came from Form 6 Arts class, whose academic performance in geography was very good, with A grade in the past Certificate of Education Examination. The other subject came from Form 5 Arts class. The performance of geography in the school of the latter subject was poor, with poor result in the final examination in the school. The topic "industrial location" had been taught in Form 5, so the two subjects were supposed to have basic understanding of the topic, though the subject who was weak in geography might have only vague ideas about industrial location.

The simulation of "locating a ball pen factory" was distributed to the subjects. Subjects were asked to write down their decision and mention the reasons for their choice, how they come to such solution on the plant location. Supplementary to the written work of the subjects, interviews were conducted. Protocols obtained from written works and supplemented by interviews were transformed into G(goal) structure diagrams as shown in figure 4.2 and 4.3. Significant differences in factors identified, sub-problems decomposed and supportive and reasoning arguments between the good and poor geography performers. After the pilot test of the "locating a ball pen factory" simulation, minor amendments were made to improve the instrument. Similar procedures were conducted to the "Locating an Oil Refinery" problem. Lastly, these two simulations could be treated as a reliable instrument for the research.

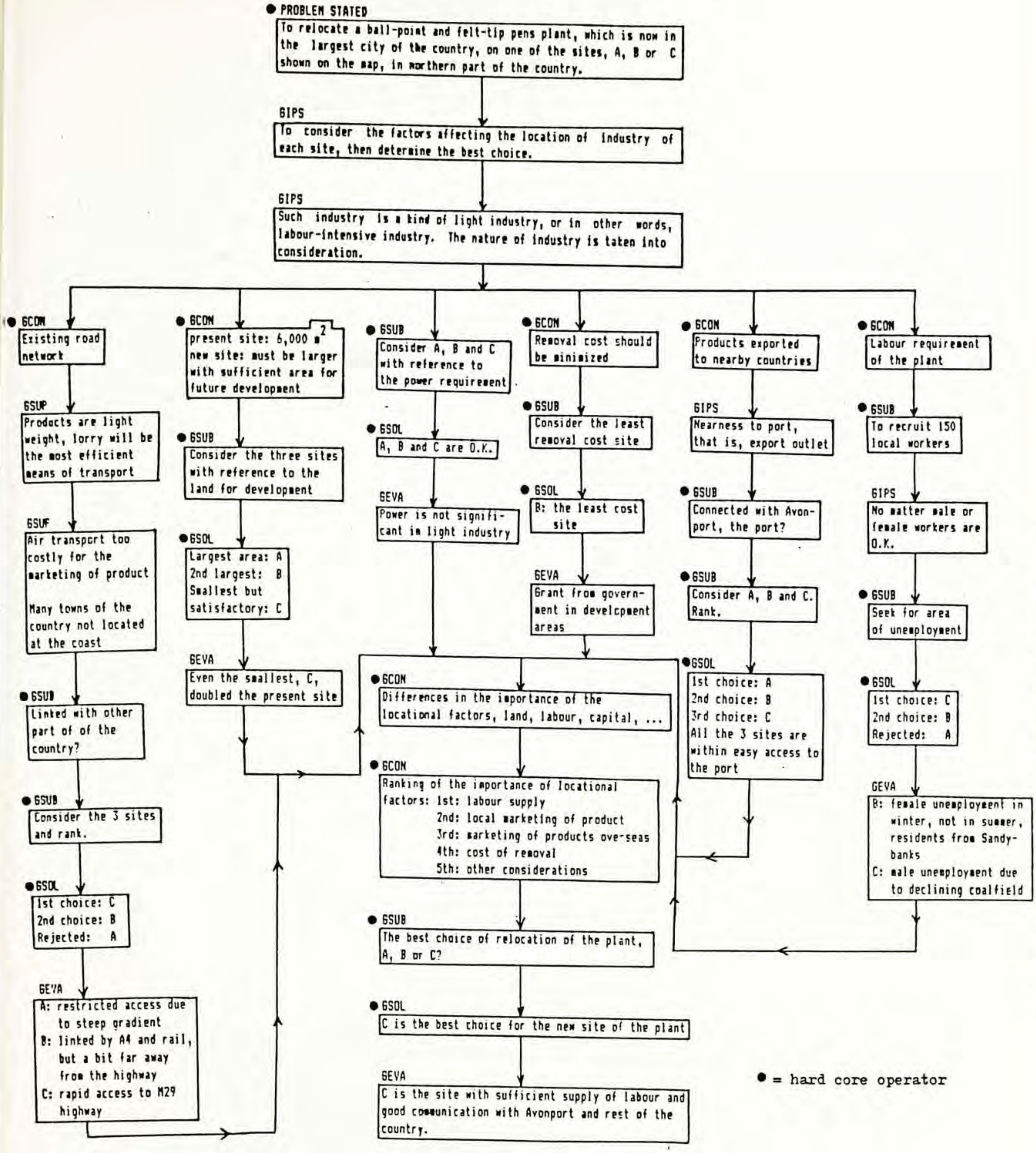

Figure 4.1. G structure of the "Locating a ball pen factory" problem based on the protocol of a social science university graduate majoring in geography.

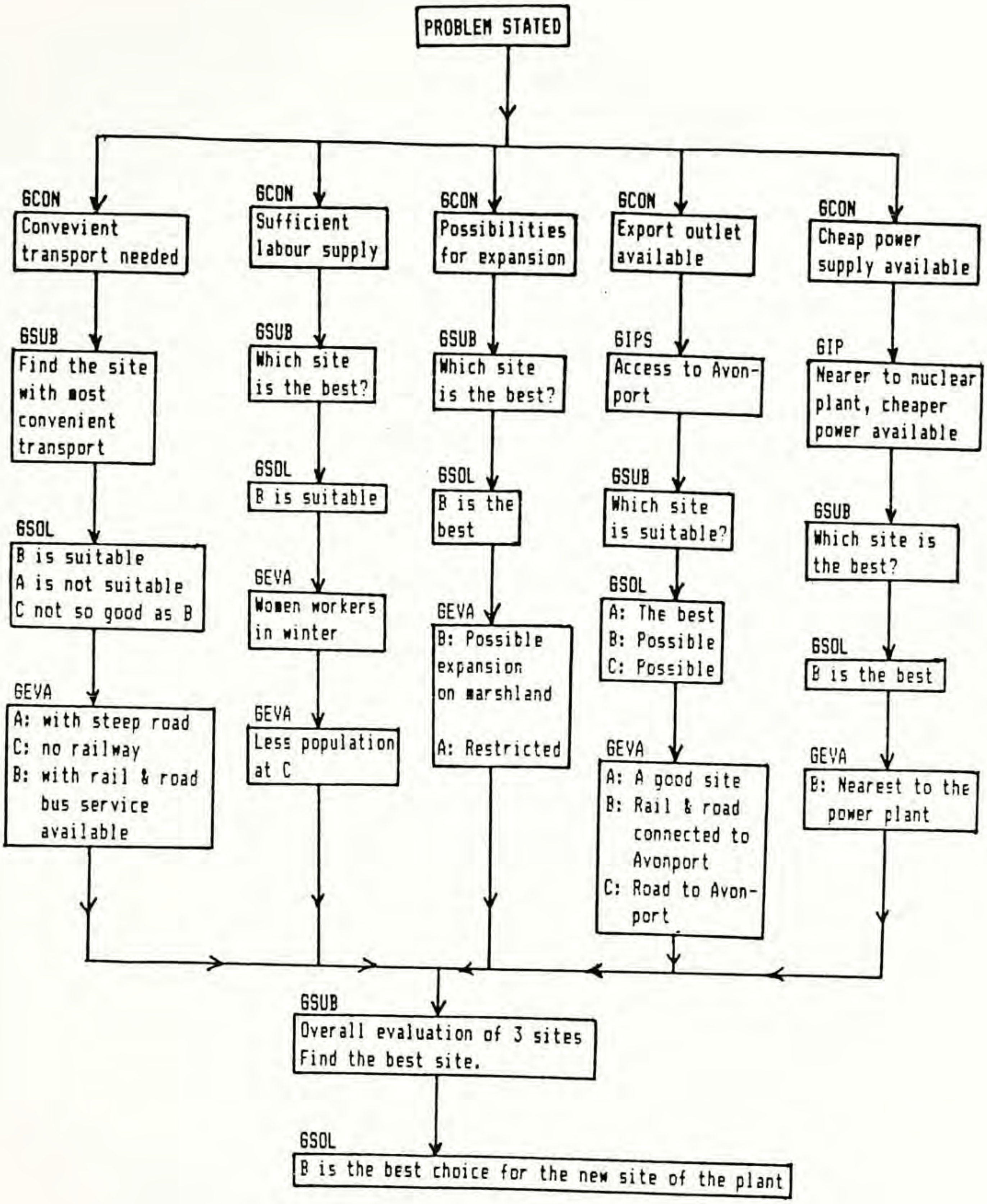

Figure 4.2. G structure of the "Locating a ball pen factory" problem based on the protocol of a Form 6 student taking geography as one of the subjects in the Advanced Level study with good performance in Certificate of Education Examination.

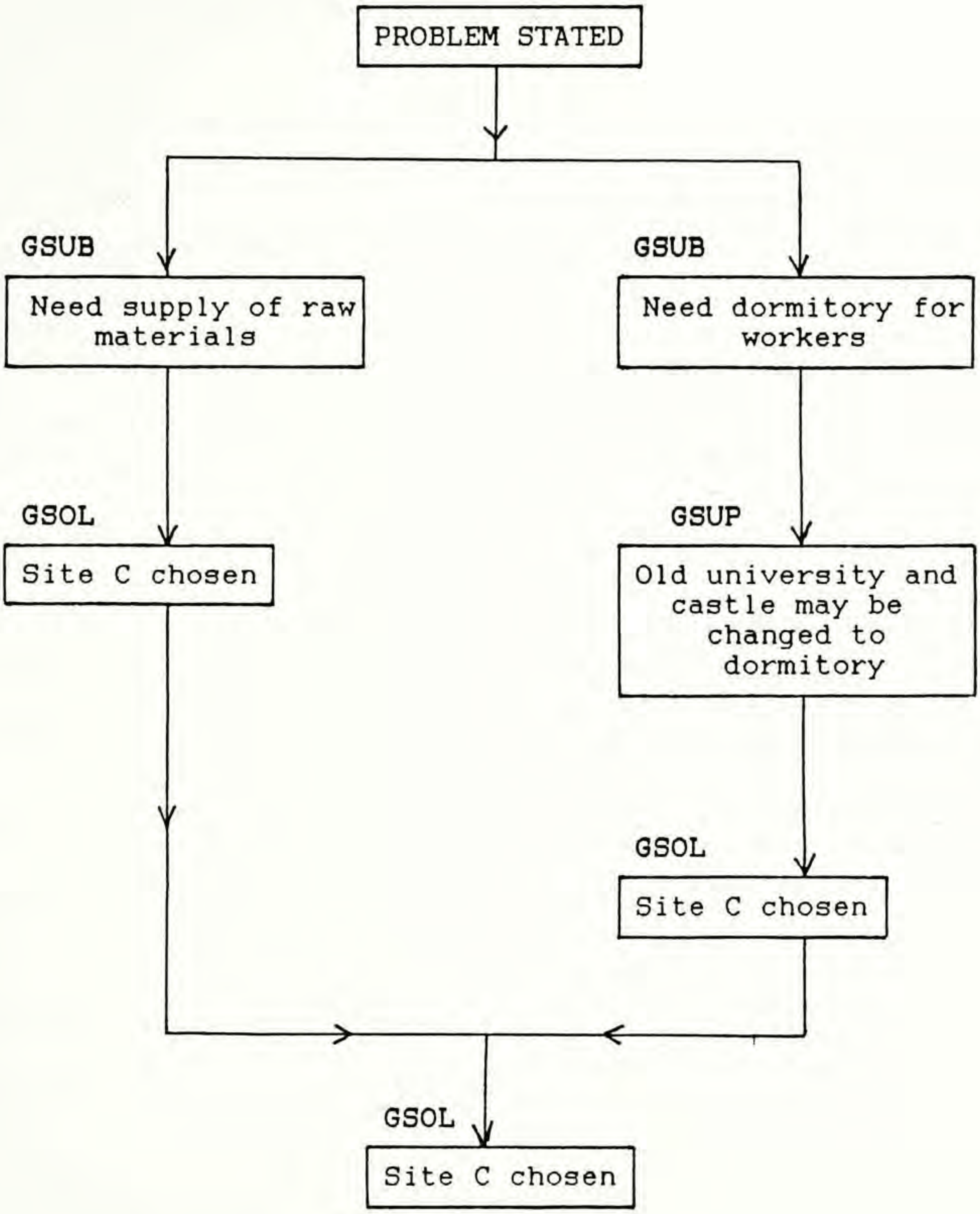

Figure 4.3 G structure of the "Locating a ball-pen factory" problem based on the protocol of a Form 5 student who did not take geography as one of the subjects in his Form 5 study and ranked in a lower position in the class in general academic performance.

P R O C E D U R E S

The procedures of the research are listed blow.

1. More than the required number of persons of each category of subjects had learned the topic of industrial location long ago, so that their knowledge structure on the topic would be quite stable. Only five subjects who could satisfy the "Knowledge" and "Ability" requirements in each of the categories were asked for further problem solving works.

2. The "Locating an oil refinery" simulation was given to the subjects two weeks after the Knowledge Test so that the undesirable factors found in connection with the Test and the Problem Solving Simulation would not be found.

3. Immediately after the written works of the problem solving simulation, an interview, based on the framework devised in the pilot study of the instruments, were given by the researcher to the subjects. Interview was treated as a supplement to the written work and a think-aloud inquiry. Materials not clearly presented in the written works as well as the problem-solving procedures and strategies were investigated in the interview. Details of the interview were recorded by tape recorder. It should be noted that there was no structured questions for the interview. However, as mentioned in the early part of this paragraph, the problem-solving framework produced by a social science university

graduate, as the one shown in figure 4.1, was treated as guidelines and scheme for the interview.

4. "Locating a ball-pen factory" simulation was given following the "Locating an Oil Refinery" simulation. Similar to the above procedures, written works and interview were taken place.

5. Materials from interviews were transcribed for further analysis.

6. Transcribed materials of verbalizations were matched with coding categories. Coding was carried out by two persons separately. Raters discussed and finally came to an agreement whenever inter-rater discrepancy was found.

7. Statistical and qualitative analysis of data were carried out.

DATA ANALYSIS

Reliability of the Knowledge Test

The reliability of the Knowledge Test was tested. Kuder-Richardson formula (K-R21 formula) was used in testing the reliability of the Knowledge Test. Result of the reliability test is reported in the previous section.

Protocol Analysis

The written materials as well as the verbal materials from interviews were used for analysis. These materials consisting of streams of verbal comments constituting of part of the solution path or the solution may be treated as protocols (Byrne, 1983). Moreover, Byrne (1983) stressed that verbal protocols can only be obtained from those who are fluent and confident verbalizers; thus children and certain clinical patients are excluded. In this research, protocols were obtained from Form 5 students, aged sixteen to eighteen. They are grown up young people and considered as well-spoken verbalizers.

Reliability of Coding

Ericsson and Simon (1984) pointed out that a central task in using verbally reported information is to make the encoding process as objective as possible. Without appropriate safeguards, the encoder, exposed to a series of ambiguous verbal statements, may encode them with a bias toward his own preferred interpretation. They further suggested several computer programs, like Mini Protocol Analysis System (MPAS), PAS-I and PAS-II, in solving the problem of reliability and validity of encoding protocols. However, none of these computer program may be available and feasible for the use in this research. In this research, the predicament of reliability and validity was unraveled in the following way. During the segmentation, units are defined that are large enough that all information for making an encoding decision is contained in a single segment.

In order to have a reliable coding of protocols, the transcribed materials will be coded by two persons. One was the researcher himself and the other was a person who had taught by the researcher about the method of coding, and had discussed with the researcher details and criteria of coding. Trial coding of transcribed materials was carried by the researcher and the other trained person. The trial coding, which serves as a warm-up practice, was also reviewed and discussed before the actual coding of the transcribed protocols. Coding of the transcribed protocols was done by the researcher and the trained assistant separately. The inter-rater reliability expressed by Pearson Product-Moment Correlationhad a moderate value of .72. Although the value was not high, it showed an acceptable degree of inter-rater reliability.

Qualitative Protocol Analysis

Qualitative protocol analysis was conducted in testing hypotheses 11 and 12. Analysis followed Newell's (1977) steps. First of all, protocol was divided into phrases. Each phrase represented a single assertion about the task or a single act of task oriented behavior. Secondly, the problem space of subject was constructed. The problem space is a hypothesis about the subject's behavior. Both the operators and information constituting a state of knowledge were set down. There may be more than one problem space. Thirdly, the "Problem Behavior Graphs" were plotted. The researcher proceeded through the protocol phrase by phrase. A "Problem Behavior Graph", like the one shown in figure 4.1, was produced with reference to the framework of social science problem solving as shown in chapter 3. The fourth step created a production system. This system attempts to capture the regularities in the search behavior.

Statistical Analysis

Hypotheses 1 to 10 were tested by Log-linear Analysis. Because of the extremely limited sample size, the non-random sampling of subjects, normality of distribution and homogeneity of variance will not be expected. Thus, analysis of variance was found unsuitable for the test of the hypotheses. Nevertheless, interaction effect of variables cannot be tested by most of the nonparametric statistical tests like Chi-square test, Mann-Whitney U test. Log-linear analysis was used in view of the fact that it does not require that data be normally distributed or sample variances equal while interaction effect can be tested. Besides aiding the search for meaningful relationships, log-linear models are in many respects similar to well-established statistical procedures such as analysis of variance and regression analysis (Reynolds, 1977). Furthermore, Knoke & Burke, (1983) pointed out that log-linear model would be a powerful tool in detailing with analysis of relationships and interactions between independent and dependent variables in cross-tabulation. Hedderson (1987) stated that the conditions when to use log-linear models. Considering this study, analysis satisfied the conditions that three or more variables should be involved and variables should be highly skewed in their distribution, or nonlinear in their effects. Hedderson (1987) emphasized that the greatest disadvantage of log-linear models is that they need a large number of cases. He further advised that the sample size should be at least five times the number of cells in the table. In the study, there were six cells while the sample size was 30, which is five times of the number of cells. So, the sample size and the number of cells fit the requirement of using log-linear model.

In conducting the log-linear analysis, a cross-tabulation, similar to the one shown in table 4.1 was established. The count of the total number of "constraints identified", "sub-problems decomposed", "supportive operators used" and "reasoning structures" derived from the subjects of the cell were entered into the cells of the cross-tabulation as observed data. Referring to table 4.1, it can be noticed that the number of subjects in each of the cells are the same, so it is reasonable to use the frequency count, that is, the total count of the number of the dependent measures evoked by the subjects in that cell as the scores of the observed data for the log-linear analysis. After setting up the cross-tabulation of the observed data, a set of expectations under the assumption that the model would be true were derived. The unit of log-linear analysis is cell probabilities or functions of cell probabilities. The expected cell frequencies of the cross-tabulation are functions of parameters representing characteristics of the categorical variables and their relationships with ratios, but not the "traditional" proportion where the cell frequency is divided by the category total (Reynolds, 1977; Knoke & Burke, 1980). Rejection or acceptance of the models would be decided after comparing the expected observations with the observed data.

Supplementary to the log-linear analysis, Kruskal-Wallis one-way ANOVA was used to test the differences in the variables knowledge bases and general learning ability, in turn, among constraints indicated, sub-problems decomposed, supportive operators used and reasoning structures found in the protocols.

Further to the testing of the null hypotheses, the level of difficulty of the two problems - the "Locating a Ball Pen Factory" problem and the "Locating an Oil Refinery" problem was tested by employing MANOVA (repeated measures).

CHAPTER 5

RESULTS AND DISCUSSION

The purpose of this study was to see if there were differences and effects of knowledge on the problem solving performance in various groups of different general learning ability. Ten null hypotheses were tested at the .05 level of statistical significance using log-linear analysis and supplemented by Kruskal-Wallis One-way ANOVA for each dependent measure using Statistical Package for the Social Sciences (SPSS). Measure of knowledge base was divided into two classes, namely the high or with knowledge base and the low or without knowledge; while the measure of general learning ability was split into three classes, namely the high, medium and low general learning abilities. The protocols of the subjects were broken down into constraints identified, sub-problems decomposed, supportive operators used and reasoning structures found, and treated as dependent measures.

In addition to the statistical tests, performance of the subjects in the problem solving process as expressed in their protocols was analyzed qualitatively. Results of the tests and analysis are presented in the following sections.

STATISTICAL ANALYSIS OF DATA

Presentation of Data

The frequency count of the "constraints identified", "sub-problems decomposed", "supportive operators used" and "reasoning structures found" in the protocols of the subjects were done. The results are cross-tabulated, general learning ability by knowledge base, in Table 5.1 to Table 5.8, where Tables 5.1, 5.3, 5.5 and 5.7 show the counting based on the "Oil Refinery" Problem, and, Tables 5.2, 5.4, 5.6, 5.8 show the counting derived from the "Ball Pen Factory Relocating Problem.

Table 5.1

Cross-tabulation of the Counting of Constraints Indicated in the Protocols of the "Oil Refinery" Problem

		General Learning Ability		
		Low	Medium	High
Knowledge Base	Low	1	1	5
	High	1	4	15

Note: The figure in the cells indicates the total frequency count of the constraints indicated in the five protocols of the five subjects.

Table 5.2

Cross-tabulation of the Counting of Constraints Indicated in the Protocols of the "Ball Pen Factory" Problem

		General Learning Ability		
		Low	Medium	High
Knowledge Base	Low	1	1	5
	High	4	9	16

Note: The figure in the cells indicates the total frequency count of the constraints indicated in the five protocols of the five subjects.

Table 5.3

Cross-tabulation of the Counting of Sub-Problems Decomposed in the Protocols of the "Oil Refinery" Problem

		General Learning Ability		
		Low	Medium	High
Knowledge Base	Low	7	10	20
	High	14	23	24

Note: The figure in the cells indicates the total frequency count of the sub-problems decomposed in the five protocols of the five subjects.

Table 5.4

Cross-tabulation of the Counting of Sub-Problems Decomposed in the Protocols of the "Ball Pen Factory" Problem

		General Learning Ability		
		Low	Medium	High
Knowledge Base	Low	7	10	20
	High	14	23	24

Note: The figure in the cells indicates the total frequency count of the sub-problems decomposed in the five protocols of the five subjects.

Table 5.5

<u>Cross-tabulation of the Counting of Supportive Operators Used in the Protocols of the "Oil Refinery" Problem</u>

		General Learning Ability		
		Low	Medium	High
Knowledge Base	Low	22	42	43
	High	32	38	51

Note: The figure in the cells indicates the total frequency count of the supportive operators found in the five protocols of the five subjects.

Table 5.6

<u>Cross-tabulation of the Counting of Supportive Operators Used in the Protocols of the "Ball Pen" Problem</u>

		General Learning Ability		
		Low	Medium	High
Knowledge Base	Low	22	40	58
	High	27	48	72

Note: The figure in the cells indicates the total frequency count of the supportive operators found in the five protocols of the five subjects.

Table 5.7

Cross-tabulation of the Counting of Reasoning Structure Found in the Protocols of the "Oil Refinery" Problem

		General Learning Ability		
		Low	Medium	High
Knowledge Base	Low	2	4	5
	High	3	8	27

Note: The figure in the cells indicates the total frequency count of the reasoning structures found in the five protocols of the five subjects.

Table 5.8

Cross-tabulation of the Counting of Reasoning Structures Found in the Protocols of the "Ball Pen" Problem

		General Learning Ability		
		Low	Medium	High
Knowledge Base	Low	1	1	1
	High	1	3	12

Note: The figure in the cells indicates the total frequency count of the reasoning structures found in the five protocols of the five subjects.

Testing of the Null Hypotheses

The null hypotheses listed in chapter 4 were tested by log-linear analysis. Results of the tests are as follows.

Null hypothesis 1 - The null hypothesis 1 as stated in Chapter 4 was tested using log-linear analysis. Number of constraints identified in the protocols of the "Ball Pen Factory Relocation Problem" were used as cell frequency. Results showing tests that K-way effects are zero are listed in table 5.9.

The analysis indicated that there was significant differences in the first order effects, knowledge bases (high, low) and general learning ability (high, medium, low). The data yielded a likelihood ratio chi-square of 25.54 at .000 probability level, with 3 degrees of freedom. Furthermore, the probability of .000 told that the first-order effects were statistically significant, meaning that they were unlikely - less than 1 time out of 1000 - to be caused by sampling error. Base on this test, null hypothesis 1 was rejected.

Null hypothesis 2 - The null hypothesis 2 as stated in Chapter 4 was tested using log-linear analysis. Number of sub-problems decomposed in the protocols in the "Ball Pen Relocation Problem" were used as cell frequency. Results showing tests that K-way effects are zero are listed in table 5.11.

The analysis indicated that there was significant differences in the first order effects, knowledge bases (high, low) and general learning ability (high, medium, low). The data yielded a likelihood ratio chi-square of 10.40 at .0155 probability level, with 3 degrees of freedom. Furthermore, the probability of .0155 told that the first-order effects were statistically significant, meaning that they were unlikely - less than 1.5 time out of 100 - to be caused by sampling error. Base on this test, null hypothesis 2 was rejected.

<u>Null hypothesis 3</u> - The null hypothesis 3 as stated in Chapter 4 was tested using log-linear analysis. Number of supportive operators used in the protocols of the "Ball Pen Relocation Problem" were used as cell frequency. Results showing tests that K-way effects are zero are listed in table 5.13.

The analysis indicated that there was significant differences in the first order effects, knowledge bases (high, low) and general learning ability (high, medium, low). The data yielded a likelihood ratio chi-square of 40.77 at .0000 probability level, with 3 degrees of freedom. Furthermore, the probability of .0000 told that the first-order effects were statistically significant, meaning that they were unlikely - less than 1 time out of 1000 - to be caused by sampling error. Base on this test, null hypothesis 3 was rejected.

<u>Null hypothesis 4</u> - The null hypothesis 4 as stated in Chapter 4 was tested using log-linear analysis. Number of reasoning

structures used in the protocols of the "Ball Pen Relocation Problem" were used as cell frequency. Results showing tests that K-way effects are zero are listed in table 5.15.

The analysis indicated that there was significant differences in the first order effects, knowledge bases (high, low) and general learning ability (high, medium, low). The data yielded a likelihood ratio chi-square of 20.18 at .0002 probability level, with 3 degrees of freedom. Furthermore, the probability of .0002 told that the first-order effects were statistically significant, meaning that they were unlikely - less than 2 time out of 1000 - to be caused by sampling error. Base on this test, null hypothesis 4 was rejected.

Null hypothesis 5 - The null hypothesis 5 as stated in Chapter 4 was tested using log-linear analysis. Number of constraints correctly identified, number of sub-problems decomposed, number of supportive operators used and reasoning structures used in the protocols of the "Ball Pen Relocation Problem" were used as cell frequency. Results showing tests that K-way effects are zero are listed in tables 5.9, 5.11, 5.13 and 5.15.

The analysis revealed no interaction between knowledge bases (high, low) and general learning ability (low, medium, high). The likelihood chi-square values for the second-order effects for "constraints", "sub-problems", "supportive operators" and "reasoning structures" were 0.91 with probability .6347 level, 0.76 with probability .6860 level, 0.02 with probability .9925 level, and 2.25 with probability .3243 level respectively. All these effects had a sample error probability of .3 and over. Base on these tests, null hypothesis 5, therefore, was not rejected.

Null hypothesis 6 - The null hypothesis 6 as stated in Chapter 4 was tested using log-linear analysis. Number of constraints identified in the protocols of the "Location of an Oil Refinery Problem" were used as cell frequency. Results showing tests that K-way effects are zero are listed in table 5.10.

The analysis indicated that there was significant differences in the first order effects, knowledge bases (high, low) and general learning ability (high, medium, low). The data yielded a likelihood ratio chi-square of 26.57 at .000 probability level, with 3 degrees of freedom. Furthermore, the probability of .000 told that the first-order effects were statistically significant, meaning that they were unlikely - less than 1 time out of 1000 - to be caused by sampling error. Base on this test, null hypothesis 6 was rejected.

Null hypothesis 7 - The null hypothesis 7 as stated in Chapter 4 was tested using log-linear analysis. Number of sub-problems decomposed in the protocols in the "Location of an Oil Refinery Problem" were used as cell frequency. Results showing tests that K-way effects are zero are listed in table 5.12.

The analysis indicated that there was significant differences in the first order effects, knowledge bases (high, low) and general learning ability (high, medium, low). The data yielded a likelihood ratio chi-square of 14.26 at .0026 probability level, with 3 degrees of freedom. Furthermore, the probability of .0026 told that the first-order effects were statistically significant, meaning that they were unlikely - less than 2.6 time out of 100 - to be caused by sampling error. Base on this test, null hypothesis 6 was rejected.

Null hypothesis 8 - The null hypothesis 8 as stated in Chapter 4 was tested using log-linear analysis. Number of supportive operators used in the protocols of the "Location of an Oil Refinery Problem" were used as cell frequency. Results showing tests that K-way effects are zero are listed in table 5.14.

The analysis indicated that there was significant differences in the first order effects, knowledge bases (high, low) and general learning ability (high, medium, low). The data yielded a likelihood ratio chi-square of 12.12 at .0070 probability level, with 3 degrees of freedom. Furthermore, the probability of .0070 told that the first-order effects were statistically significant, meaning that they were unlikely - less than 7 time out of 100 - to be caused by sampling error. Base on this test, null hypothesis 8 was rejected.

Null hypothesis 9 - The null hypothesis 9 as stated in Chapter 4 was tested using log-linear analysis. Number of reasoning structures used in the protocols of the "Location of an Oil Refinery Problem" were used as cell frequency. Results showing tests that K-way effects are zero are listed in table 5.16.

The analysis indicated that there was significant differences in the first order effects, knowledge bases (high, low) and general learning ability (high, medium, low). The data yielded a likelihood ratio chi-square of 39.55 at .0000 probability level, with 3 degrees of freedom. Furthermore, the probability of .0000 told that the first-order effects were statistically significant, meaning that they were unlikely - less than 1 time out of 1000 - to be caused by sampling error. Base on this test, null hypothesis 9 was rejected.

Null hypothesis 10 - The null hypothesis 10 as stated in Chapter 4 was tested using log-linear analysis. Number of constraints correctly identified, number of sub-problems decomposed, number of supportive operators used and reasoning structures used in the protocols of the "Location of an Oil Refinery Problem" were used as cell frequency. Results showing tests that K-way effects are zero are listed in tables 5.10, 5.12, 5.14 and 5.16.

The analysis revealed no interaction between knowledge bases (high, low) and general learning ability (low, medium, high). The likelihood chi-square values for the second-order effects for "constraints", "sub-problems", "supportive operators" and "reasoning structures" were 0.63 with probability .7286 level, 2.07 with probability .3556 level, 1.89 with probability .3898 level, and 2.45 with probability .2946 level respectively. All these effects had a sample error probability of .3 and over. Base on these tests, null hypothesis 10, therefore, was not rejected.

Table 5.9

<u>Results of Tests that K-way Effects are Zero in Log-Linear Analysis:-</u>
<u>Variables Knowledge Bases by General Learning Ability;</u>
<u>With Constraints Indicated in the Protocols as Frequency Counts in the Cells;</u>
<u>in "Locating a Ball Pen Factory" Problem</u>

Problem	K	DF	Likelihood Chi-square	Probability	Pearson Chi-square	Probability
Ball Pen Factory	1	3	25.542	.0000	26.507	.0000
Problem	2	2	.909	.6347	.826	.6617

Note: DF = degree of freedom

Table 5.10

<u>Results of Tests that K-way Effects are Zero in Log-Linear Analysis:-</u>
<u>Variables Knowledge Bases by General Learning Ability;</u>
<u>With Constraints Indicated in the Protocols as Frequency Counts in the Cells;</u>
<u>in "Locating an Oil Refinery" Problem</u>

Problem	K	DF	Likelihood Chi-square	Probability	Pearson Chi-square	Probability
Oil Refinery	1	3	26.573	.0000	32.074	.0000
Problem	2	2	.633	.7286	.704	.7033

Note: DF = degree of freedom

Table 5.11

Results of Tests that K-way Effects are Zero in Log-Linear Analysis:-
Variables Knowledge Bases by General Learning Ability;
With Sub-problems Decomposed in the Protocols as Frequency Counts in the Cells;
in "Locating a Ball Pen Factory" Problem

Problem	K	DF	Likelihood Chi-square	Probability	Pearson Chi-square	Probability
Ball Pen Factory Problem	1	3	10.398	.0155	9.871	.0197
	2	2	.754	.6860	.754	.6859

Note: DF = degree of freedom

Table 5.12

Results of Tests that K-way Effects are Zero in Log-linear Analysis:-
Variables Knowledge Bases by General Learning Ability;
With Sub-problems Decomposed in the Protocols as Frequency Counts in the Cells;
in "Locating an Oil Refinery" Problem

Problem	K	DF	Likelihood Chi-square	Probability	Pearson Chi-square	Probability
Oil Refinery Problem	1	3	14.260	.0026	13.202	.0042
	2	2	2.068	.3556	2.064	.3562

Note: DF = degree of freedom

Table 5.13

Results of Tests that K-way Effects are Zero in Log-Linear Analysis:-
Variables Knowledge Bases by General Learning Ability;
With Supportive Operators Used in the Protocols as Frequency Counts in the Cells;
in "Locating a Ball Pen Factory" Problem

Problem	K	DF	Likelihood Chi-square	Probability	Pearson Chi-square	Probability
Ball Pen Factory Problem	1	3	40.772	.0000	40.064	.0000
	2	2	.015	.9925	.015	.9925

Note: DF = degree of freedom

Table 5.14

Results of Tests that K-way Effects are Zero in Log-Linear Analysis:-
Variables Knowledge Bases by General Learning Ability;
With Supportive Operators Used in the Protocols as Frequency Counts in the Cells;
in "Locating an Oil Refinery" Problem

Problem	K	DF	Likelihood Chi-square	Probability	Pearson Chi-square	Probability
Oil Refinery Problem	1	3	12.120	.0070	11.330	.0101
	2	2	1.884	.3898	1.880	.3906

Note: DF = degree of freedom

Table 5.15

Results of Tests that K-way Effects are Zero in Log-Linear Analysis:-
Variables Knowledge Bases by General Learning Ability;
With Reasoning Structure Operators Found in the Protocols as Frequency Counts in the Cells
in "Locating a Ball Pen Factory" Problem

Problem	K	DF	Likelihood Chi-square	Probability	Pearson Chi-square	Probability
Ball Pen Factory	1	3	20.176	.0002	27.922	.0000
Problem	2	2	2.252	.3243	2.657	.2649

Note: DF = degree of freedom

Table 5.16

Results of Tests that K-way Effects are Zero in Log-Linear Analysis:-
Variables Knowledge Bases by General Learning Ability;
With Reasoning Structure Operators Found in the Protocols as Frequency Counts in the Cells
in "Locating an Oil Refinery" Problem

Problem	K	DF	Likelihood Chi-square	Probability	Pearson Chi-square	Probability
Oil Refinery	1	3	39.545	.0000	52.157	.0000
Problem	2	2	2.444	.2946	2.557	.2784

Note: DF = degree of freedom

In addition to the log-linear analysis, Kruskal-Wallis One-way ANOVA was used to test the differences in the variables knowledge bases and general learning ability, in turn, among constraints indicated, sub-problems decomposed, supportive operators used and reasoning structures found in the protocols. Results of the tests are shown in Tables 5.17 to 5.32.

The tests indicated that there was significant difference in general learning ability among constraints indicated, sub-problems decomposed, supportive operators used in both the "Location of Oil Refinery Problem" and the "Ball Pen Factory Relocation Problem"; and significant difference in general learning ability among reasoning structure operators found in the "Ball Pen Factory Relocation Problem" at .05 significant level.

With reference to the knowledge bases, the tests revealed that there was significant difference in the knowledge base among constraints indicated in the "Ball Pen Relocation Problem", and among sub-problems decomposed in both the "Location of Oil Refinery Problem" and the "Ball Pen Factory Relocation Problem" at .05 significant level.

Table 5.17

Result of Kruskal-Wallis One-way ANOVA : Constraints Indicated in Protocol by General Learning Ability in "Locating a Ball Pen Factory" Problem

Problem	Chi-square	Significance	Corrected for Ties Chi-square	Corrected for Ties Significance
Ball Pen Factory Problem	8.3716	.0152	9.4029	.0091

Table 5.18

Result of Kruskal-Wallis One-way ANOVA : Constraints Indicated in Protocol by General Learning Ability in "Locating an Oil Refinery" Problem

Problem	Chi-square	Significance	Corrected for Ties Chi-square	Corrected for Ties Significance
Oil Refinery Problem	13.1826	.0014	15.4191	.0004

Table 5.19

Result of Kruskal-Wallis One-way ANOVA : Sub-problems Decomposed in Protocol by General Learning Ability in "Locating a Ball Pen Factory" Problem

Problem	Chi-square	Significance	Corrected for Ties Chi-square	Significance
Ball Pen Factory Problem	13.8510	.0010	15.1595	.0005

Table 5.20

Result of Kruskal-Wallis One-way ANOVA : Sub-problems Decomposed in Protocol by General Learning Ability in "Locating a Ball Pen Factory" Problem

Problem	Chi-square	Significance	Corrected for Ties Chi-square	Significance
Oil Refinery Problem	11.8458	.0027	12.3715	.0021

Table 5.21

<u>Result of Kruskal-Wallis One-way ANOVA : Supportive Operators Used in Protocol by General Learning Ability in "Locating a ball Pen Factory" Problem</u>

Problem	Chi-square	Significance	Corrected for Ties Chi-square	Corrected for Ties Significance
Ball Pen Factory Problem	22.3594	.0000	22.5702	.0000

Table 5.22

<u>Result of Kruskal-Wallis One-way ANOVA : Supportive Operators Used in Protocol by General Learning Ability in "Locating an Oil Refinery" Problem</u>

Problem	Chi-square	Significance	Corrected for Ties Chi-square	Corrected for Ties Significance
Oil Refinery Problem	9.88813	.0071	10.0150	.0067

Table 5.23

Result of Kruskal-Wallis One-way ANOVA : Reasoning Structure Found in Protocol by General Learning Ability in "Locating a Ball Pen Factory" Problem

Problem	Chi-square	Significance	Corrected for Ties Chi-square	Significance
Ball Pen Factory Problem	1.0297	.5976	1.7117	.4249

Table 5.24

Result of Kruskal-Wallis One-way ANOVA : Reasoning Structure Found in Protocol by General Learning Ability in "Locating an Oil Refinery" Problem

Problem	Chi-square	Significance	Corrected for Ties Chi-square	Significance
Oil Refinery Problem	4.0748	.1304	4.5802	.1013

Table 5.25

Result of Kruskal-Wallis One-way ANOVA : Constraints Indicated in Protocol by Knowledge Base in "Locating a Ball Pen Factory" Problem

Problem	Chi-square	Significance	Corrected for Ties Chi-square	Corrected for Ties Significance
Ball Pen Factory Problem	11.1488	.0008	12.5222	.0004

Table 5.26

Result of Kruskal-Wallis One-way ANOVA : Constraints Indicated in Protocol by Knowledge Base in "Locating an Oil Refinery" Problem

Problem	Chi-square	Significance	Corrected for Ties Chi-square	Corrected for Ties Significance
Oil Refinery Problem	1.7616	.1844	2.0606	.1511

Table 5.27

Result of Kruskal-Wallis One-way ANOVA : Sub-problems Decomposed in Protocol by Knowledge Base in "Locating a Ball Pen Factory" Problem

Problem	Chi-square	Significance	Corrected for Ties Chi-square	Corrected for Ties Significance
Ball Pen Factory Problem	4.8327	.0279	5.2892	.0215

Table 5.28

Result of Kruskal-Wallis One-way ANOVA : Sub-problems Decomposed in Protocol by Knowledge Base in "Locating an Oil Refinery" Problem

Problem	Chi-square	Significance	Corrected for Ties Chi-square	Corrected for Ties Significance
Oil Refinery Problem	7.8387	.0051	8.1866	.0042

Table 5.29

Result of Kruskal-Wallis One-way ANOVA : Supportive Operators Used in Protocol by Knowledge Base in "Locating a Ball Pen Factory" Problem

Problem	Chi-square	Significance	Corrected for Ties Chi-square	Corrected for Ties Significance
Ball Pen Factory Problem	.9501	.3297	.9591	.3274

Table 5.30

Result of Kruskal-Wallis One-way ANOVA : Supportive Operators Used in Protocol by Knowledge Base in "Locating an Oil Refinery" Problem

Problem	Chi-square	Significance	Corrected for Ties Chi-square	Corrected for Ties Significance
Oil Refinery Problem	.7230	.3952	.7328	.3920

Table 5.31

Result of Kruskal-Wallis One-way ANOVA : Reasoning Structure Found in Protocol by Knowledge Base in "Locating a Ball Pen Factory" Problem

Problem	Chi-square	Significance	Corrected for Ties Chi-square	Significance
Ball Pen Factory Problem	.6542	.4186	1.0875	.2970

Table 5.32

Result of Kruskal-Wallis One-way ANOVA : Reasoning Structure Found in Protocol by Knowledge Base in "Locating an Oil Refinery" Problem

Problem	Chi-square	Significance	Corrected for Ties Chi-square	Significance
Oil Refinery Problem	1.9308	.1647	2.1702	.1407

Test of the Levels of Difficulty of the Two Problems

Additional to the testing of the null hypotheses, the level of difficulty of the two problems - the "Locating a Ball Pen Factory" problem and the "Locating an Oil Refinery" problem, was tested as well. Since each subject was asked to complete the two problems of different difficulties, MANOVA (repeated measures) was performed in the testing of difference of the level of difficulty of the two problems on four dependent variables: the number of constraints identified, the sub-problems decomposed, the supportive operators used and the reasoning structures found in the protocols. Each dependent variable was analyzed, in turn, in a repeated measures of MANOVA, in order to investigate the differences between the two problems.

Results of the tests are shown in tables 5.33 to 5.36. Significant difference between the two levels of difficulty on the problems was made by the number of supportive operators and reasoning structures used in the protocols with $\underline{F}(1,29) = 5.87$, $\underline{p} < .05$ and $\underline{F}(1,29) = 6.59$, $\underline{p} < .05$ respectively. However, there was no significant difference between the two problems with the number of constraints identified and the sub-problems decomposed in the protocols at .05 significant level.

Statistical significant differences between the two problems by the number of supportive operators and reasoning structures confirmed that the two problems of industrial location were of different difficulty level. The fact that there was no statistical significant difference between the problems by the number of constraints and sub-problems might be explained by the nature of these two problems. The two problems -- "Locating a Ball Pen Factory" and "Locating an Oil Refinery" -- were of the same nature, both relating to location of industry. Factors affecting the location of a ball pen factory can be applied to the location of an oil refinery. These factors corresponded to the sub-problems decomposed by the problem solvers. Hence, no significant difference could be revealed by the number of sub-problems. Factors affecting the decision should be linked with the constraints, so no significant difference could be established by the number of constraints.

Table 5.33

Result of MANOVA (Repeated Measures) in Constraints Indicated in the Protocols with the Problems of Different Levels of Difficulty as Within-Subject Effect

Source of Variation	SS	df	MS	F	Signifance of F
Within cell	10.15	29	.35		
Levels of difficulty of problems	1.35	1	1.35	3.86	.059

Table 5.34

Result of MANOVA (Repeated Measures) in Sub-problems Decomposed in the Protocols with the Problems of Different Levels of Difficulty as Within-Subject Effect

Source of Variation	SS	df	MS	F	Signifance of F
Within cell	10.93	29	.38		
Levels of difficulty of problems	.07	1	.07	.18	.677

Table 5.35

<u>Result of MANOVA (Repeated Measures) in Supportive Operators Used in the Protocols with the Problems of Different Levels of Difficulty as Within-Subject Effect</u>

Source of Variation	SS	df	MS	F	Signifance of F
Within cell	125.15	29	4.32		
Levels of difficulty of problems	25.35	1	25.35	5.87	.022

Table 5.36

<u>Result of MANOVA (Repeated Measures) in Reasoning Structurs Found in the Protocols with the Problems of Different Levels of Difficulty as Within-Subject Effect</u>

Source of Variation	SS	df	MS	F	Signifance of F
Within cell	66.00	29	2.28		
Levels of difficulty of problems	15.00	1	15.00	6.59	.016

QUALITATIVE ANALYSIS OF DATA

Protocols of the subjects were analyzed. Protocols were rewritten in terms of the G structures as proposed by Voss and his associates (1983a), and expressed in the form of tree-like flow diagram. Examples of these tree-like flow diagrams are shown in figures 5.1 to 5.9. Best performance of each category, as judged by the author and another rater, was chosen as examples. However, the reasoning structures of the protocols were also noted in terms of the framework put forth by Voss, Greene, Post and Penner (1983) as listed in chapter 4. An example of the reasoning structure is shown in table 5.37.

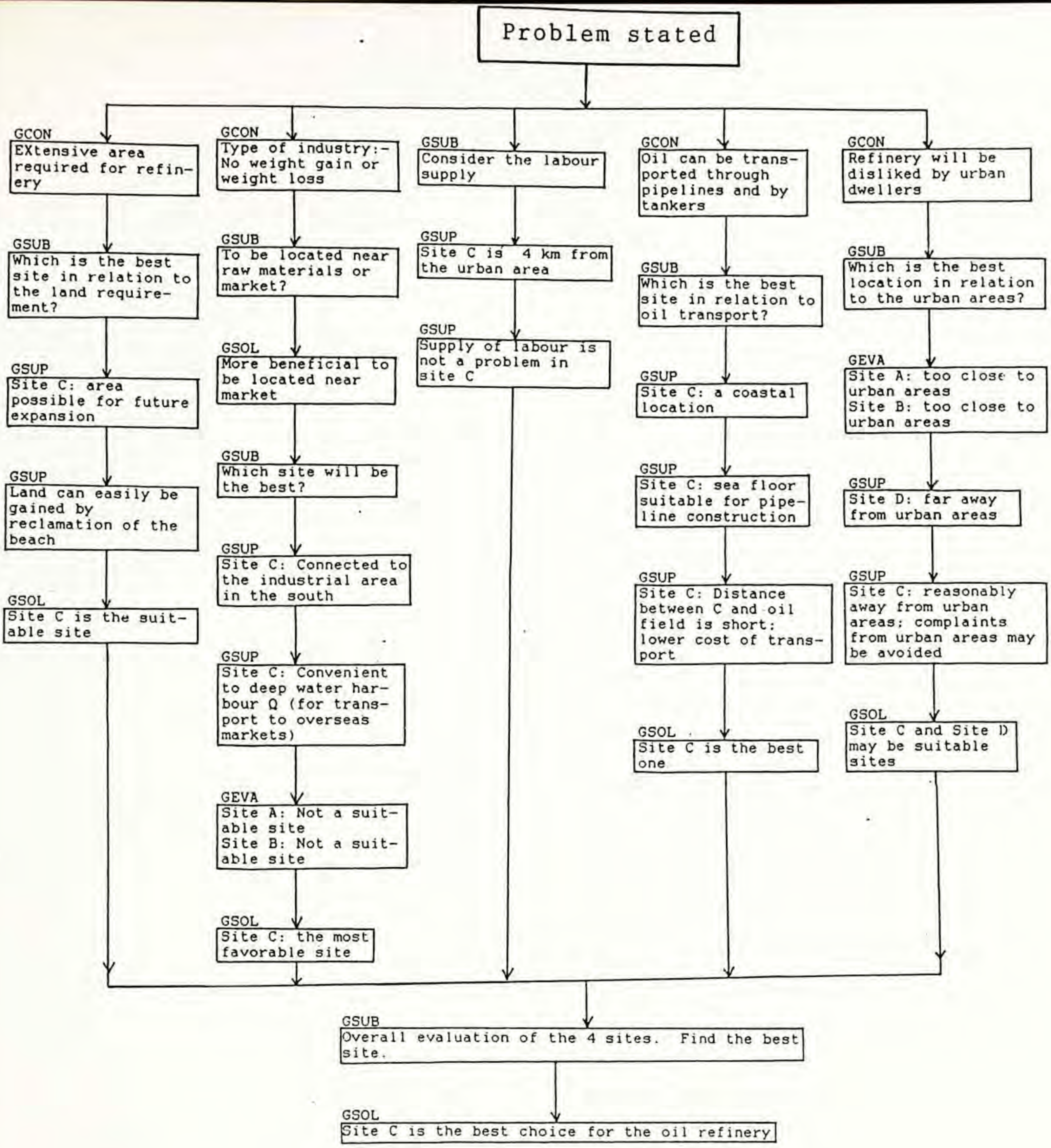

Figure 5.1. G structure of the "Locating an Oil Refinery" problem based on the protocol of a subject with knowledge base and of high general learning ability.

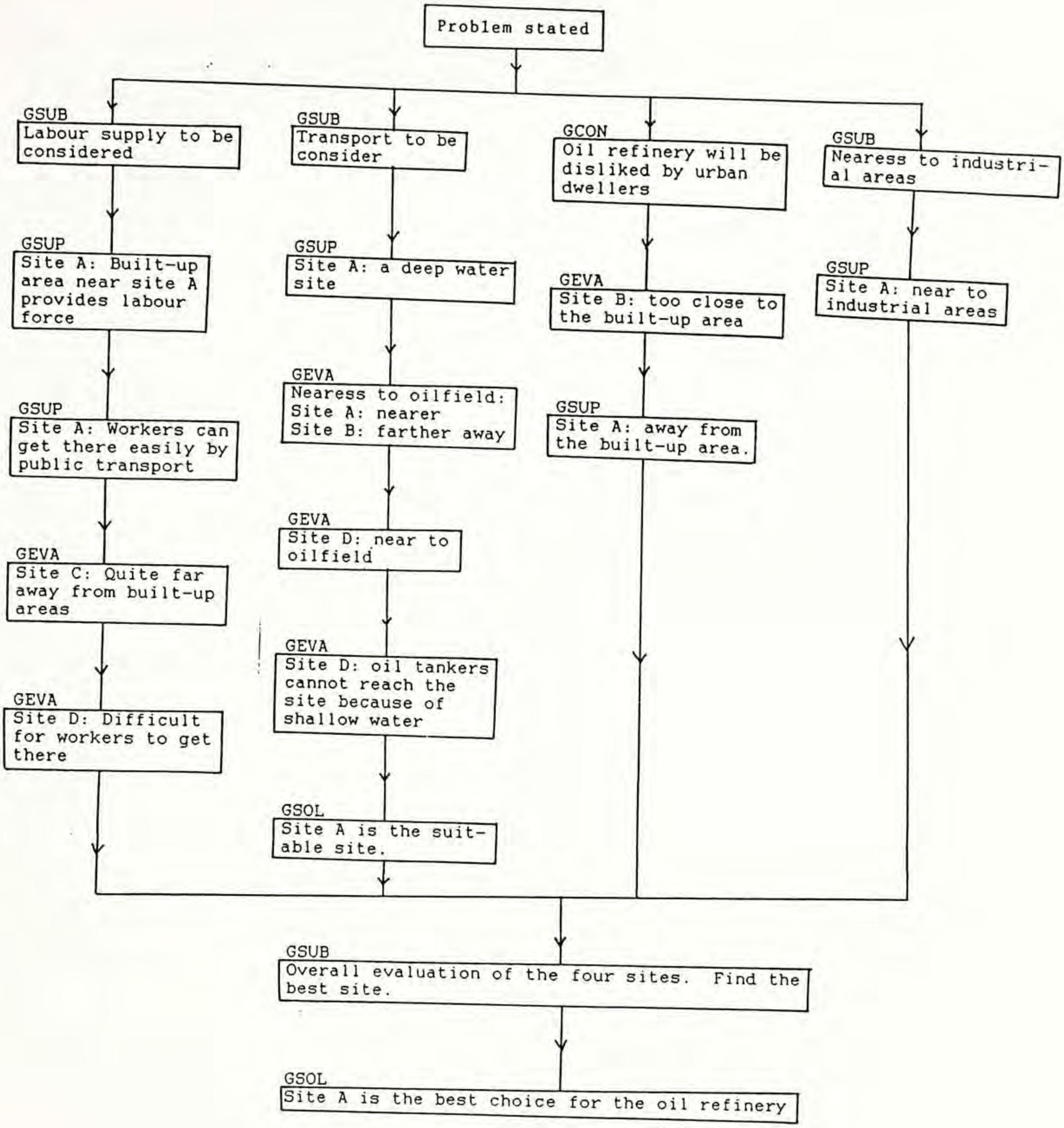

Figure 5.2. G structure of the "Locating an Oil refinery" problem based on the protocol of a subject without knowledge base and of high general learning ability.

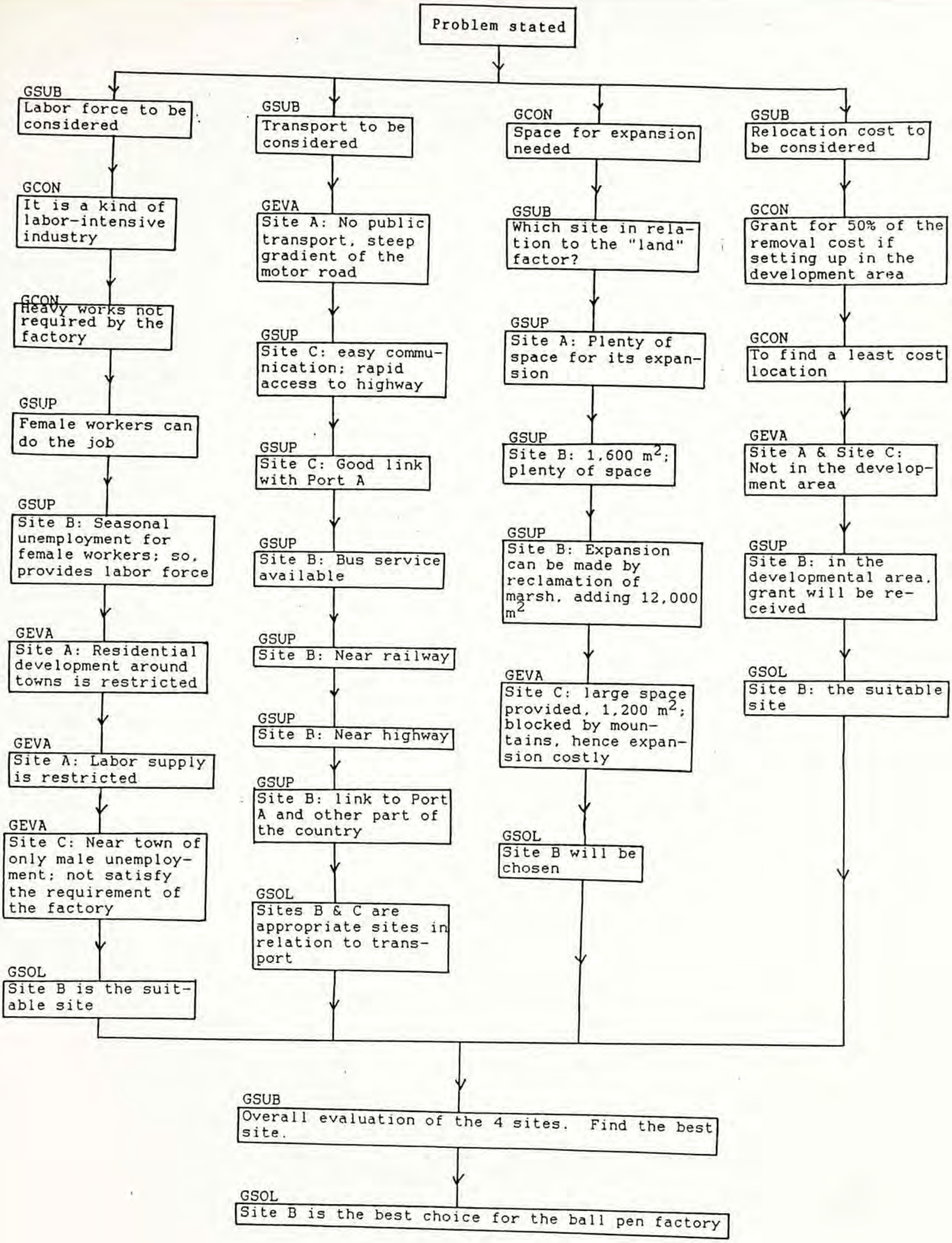

Figure 5.3. G structure of the "Locating a Ball Pen Factory" problem based on the protocol of a subject with knowledge base and of high general learning ability.

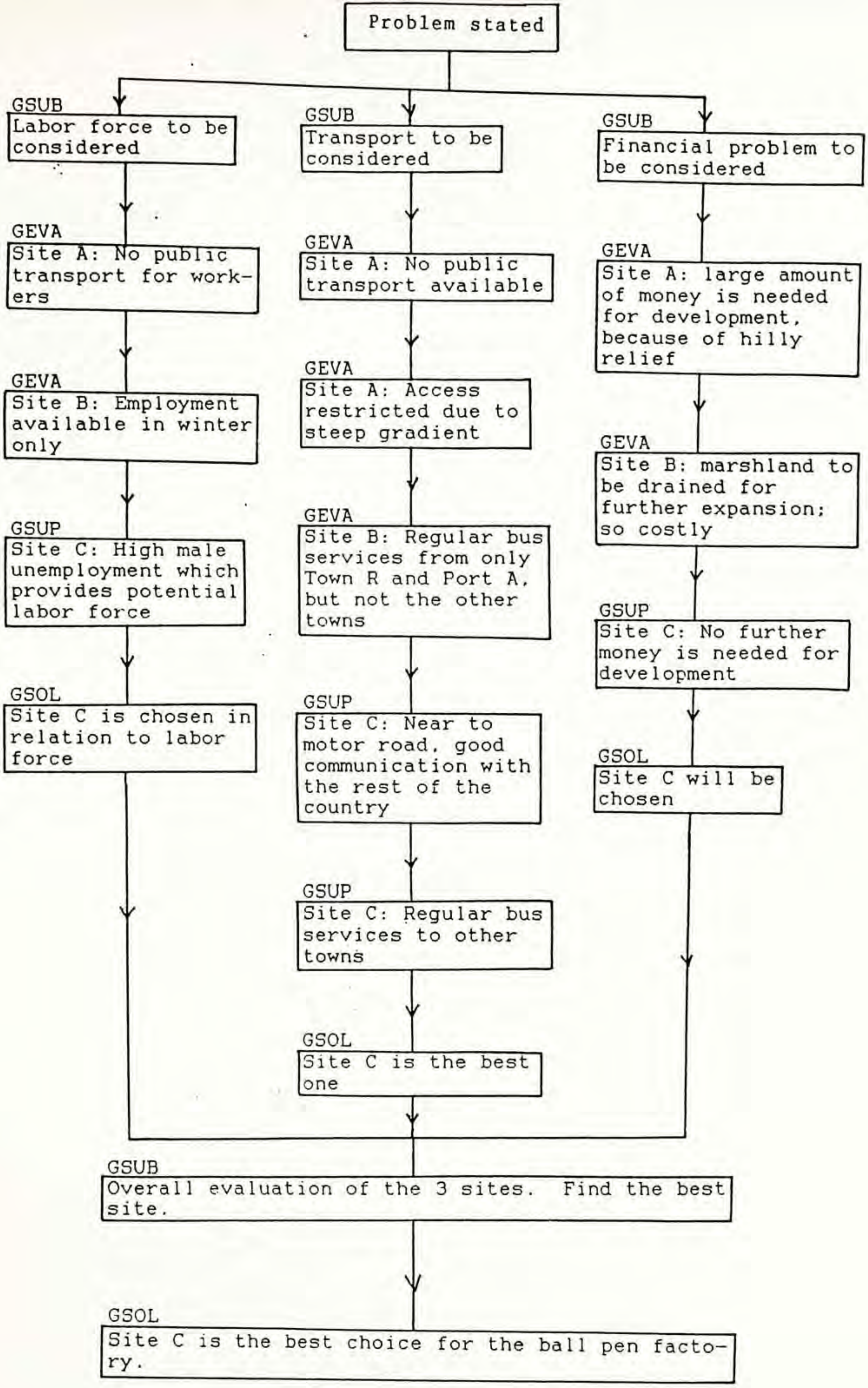

Figure 5.4. G structure of the "Locating a Ball Pen Factory" problem based on the protocol of a subject without knowledge base and of high general learning ability.

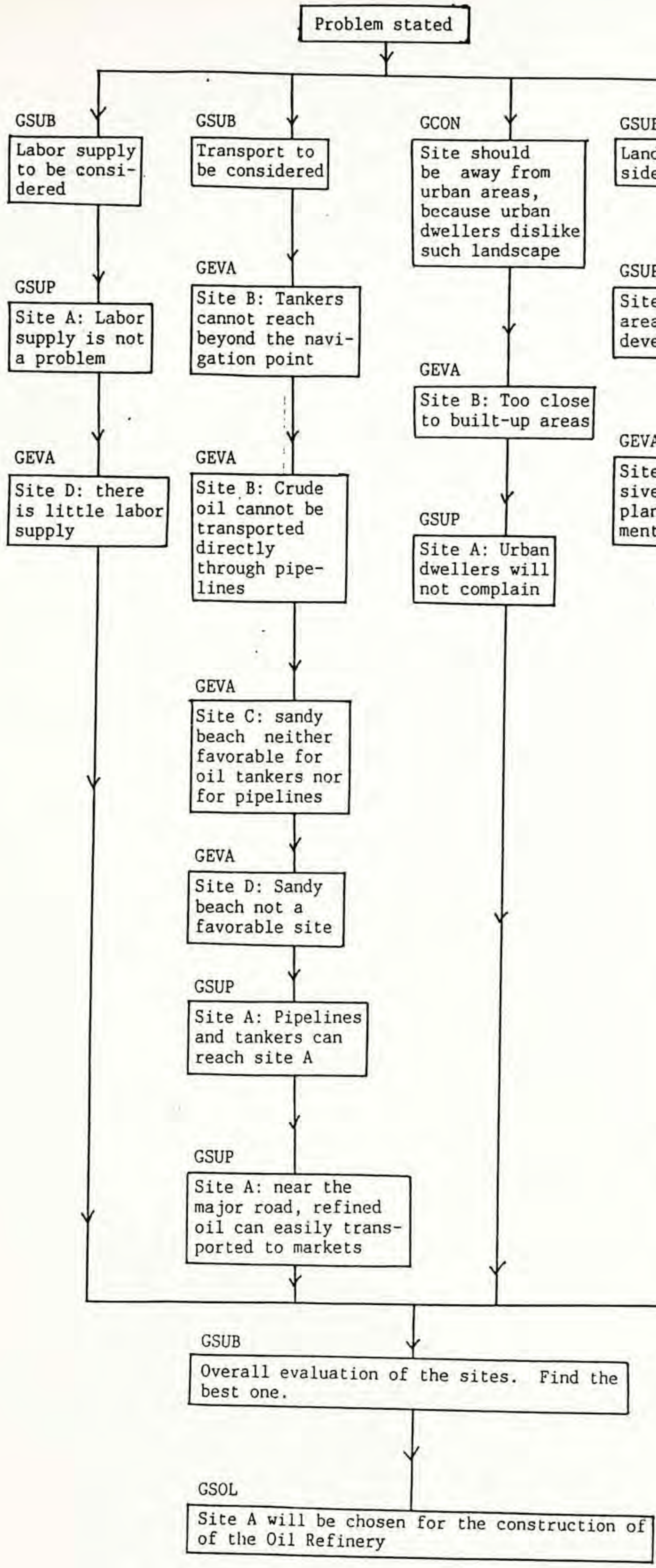

Figure 5.5. G structure of the "Locating an Oil Refinery" problem based on the protocol of a subject with knowledge base and of medium general learning ability.

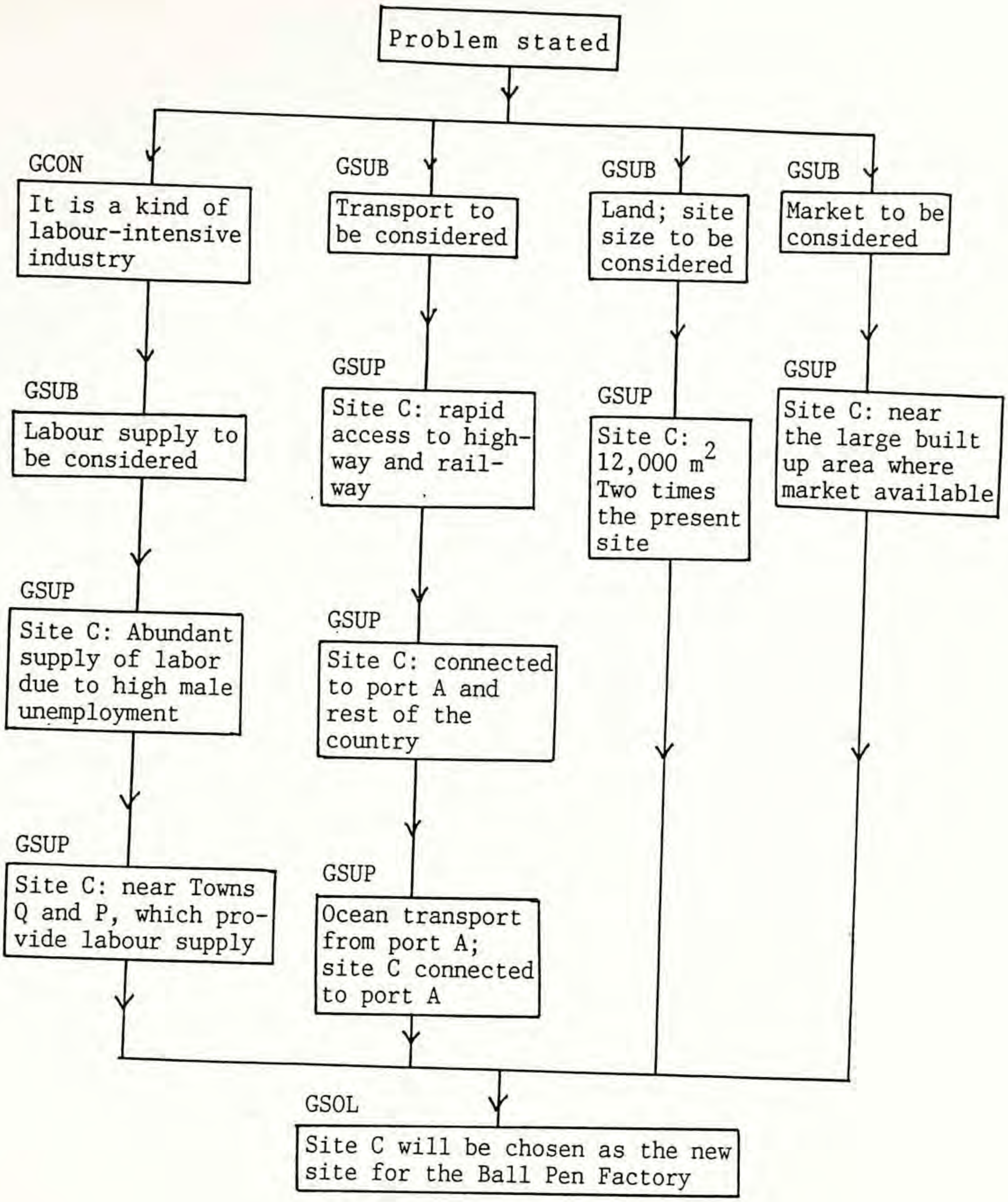

Figure 5.6. G structure of the "Locating a Ball Pen Factory" problem based on the protocol of a subject with knowledge base and of medium general learning ability

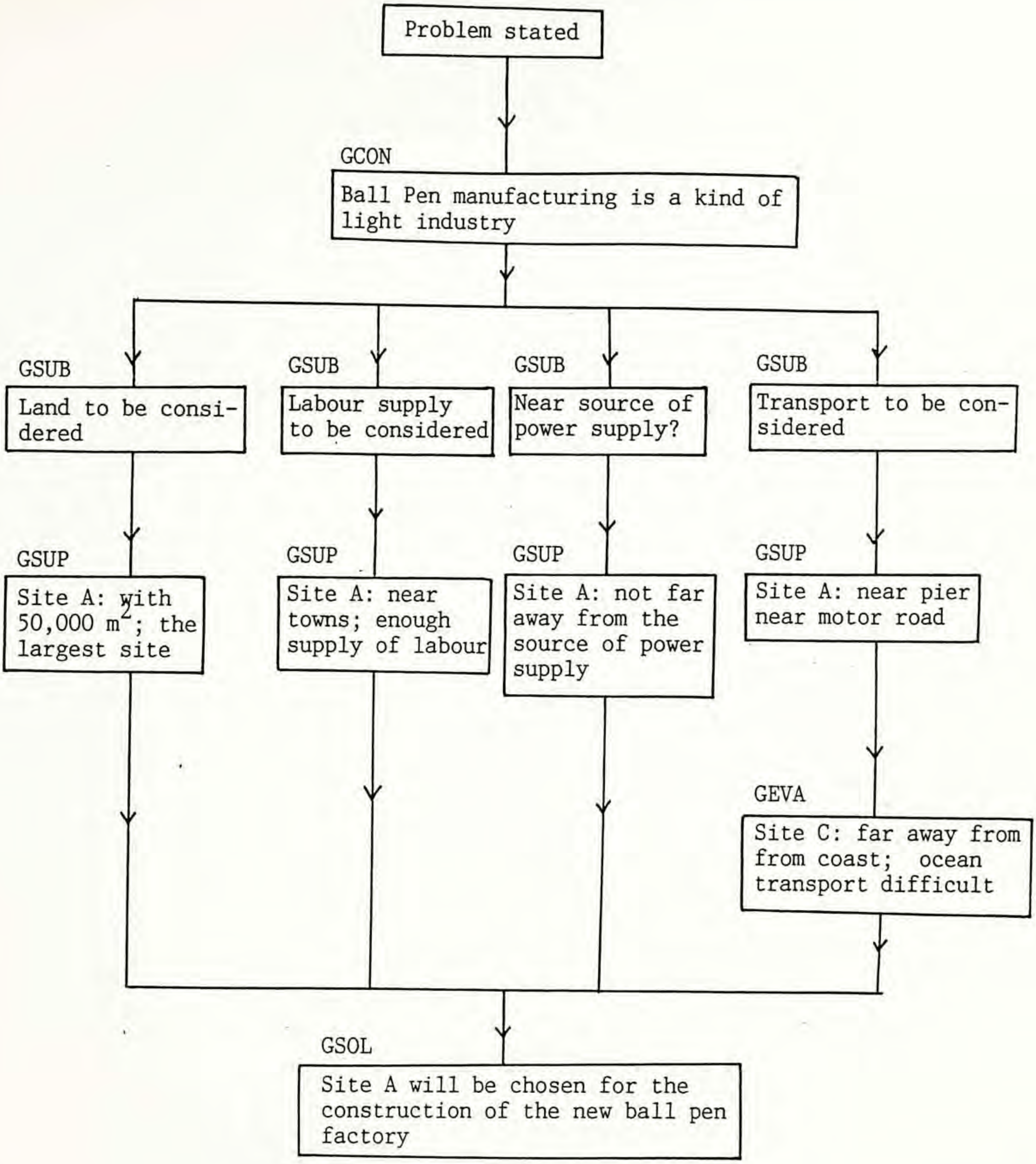

Figure 5.7. G structure of the "Locating a Ball Pen Factory" problem based on the protocol of a subject with knowledge base and of low general learning ability

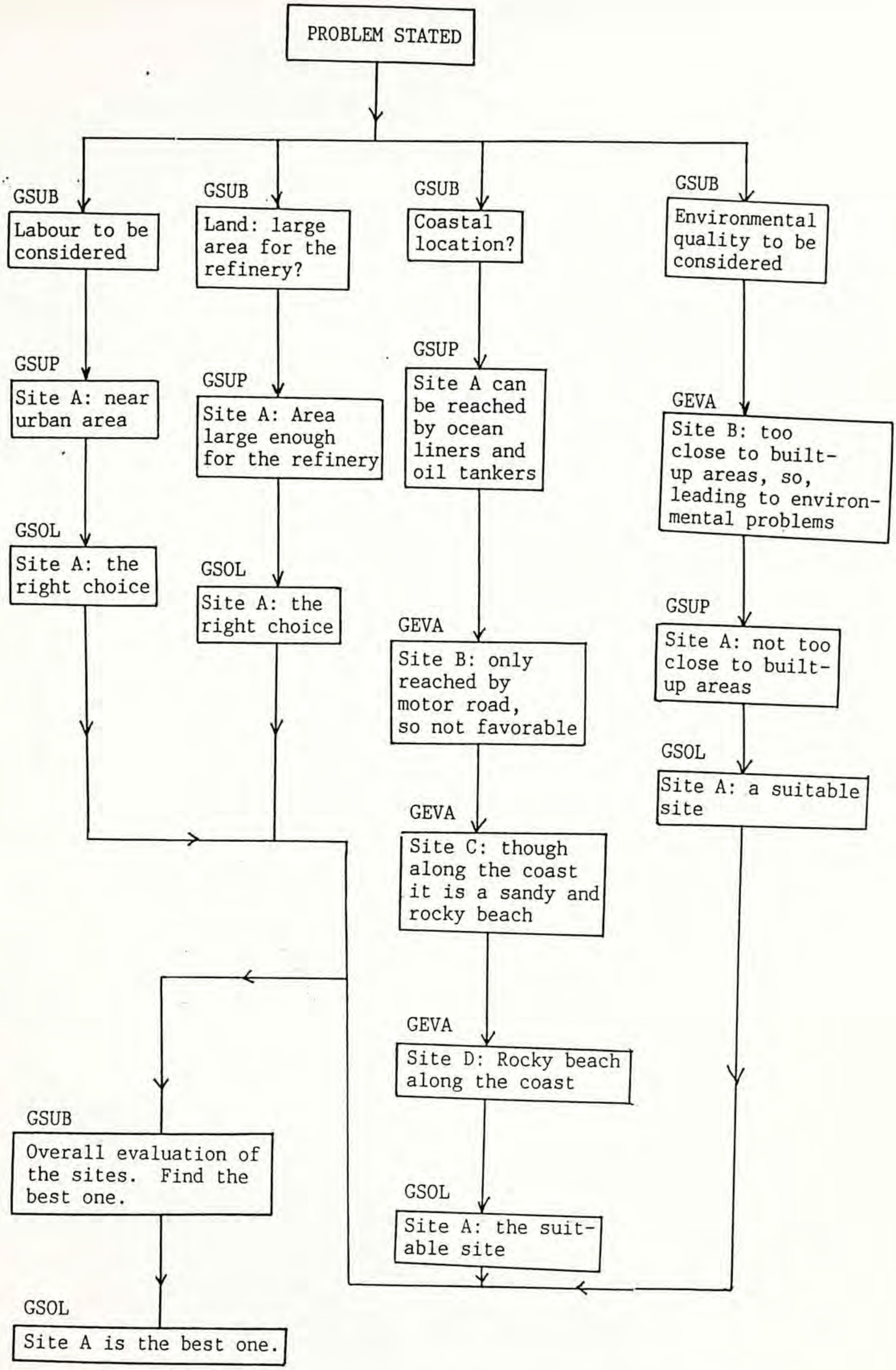

Figure 5.8. G structure of the "Locating an Oil Refinery" problem based on the protocol of a subject without knowledge base and of low general learning ability.

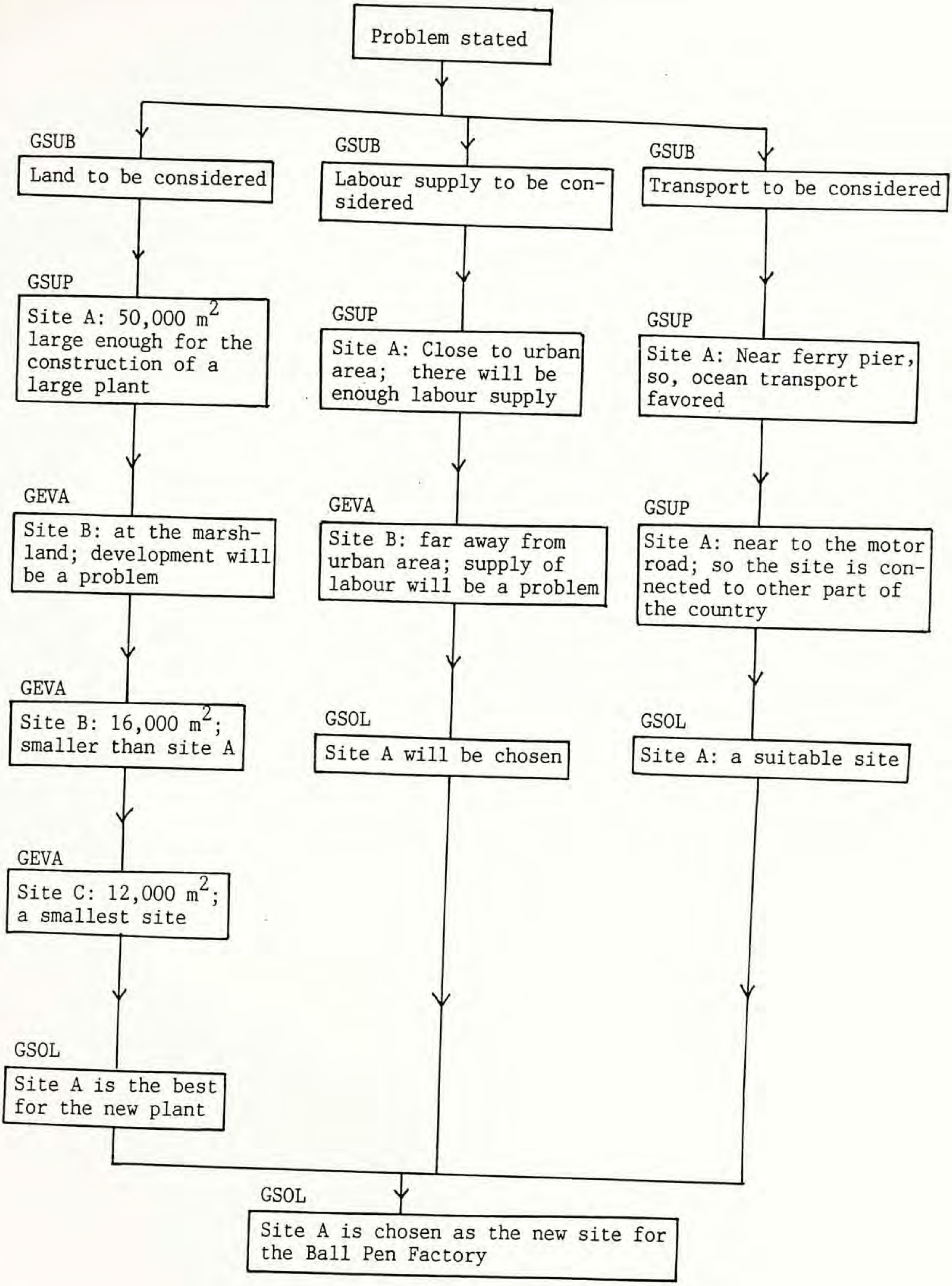

Figure 5.9. G structure of the "Locating a Ball Pen Factory" problem based on the protocol of a subject without knowledge base and of low general learning ability

Table 5.37

<u>Sample of the Reasoning Argument Structures from the Protocol of a Subject</u>

RARG	Town R can provide sufficient labour
RREA	since there will be seasonly unemployment in winter.
RREA	Besides, town R provides a lot of female workers.
RSAS	Ball pen industry is labor-intensive, needs delicate techniques
ROUT	so female labour is very suitable.
RELA	Railway and regular bus service allow workers go to work in town R easily.

DISCUSSION

Sub-problems decomposed by the subjects

The sub-problems decomposed in social science problems could be described in another way as the underlying factors governing the solution. In the industrial location problems, sub-problems decomposed were the factors affecting the industrial location. These factors were actually common sense factors. Even the man in the street could say that "land", "labor", "transport" would affect the location of a factory. From the protocols of the subjects, it is found that subjects of both high and low knowledge bases could decompose elementary factors affecting industrial locations, like "land", "labor". However, the way of explanation and the details of elaboration of these factors vary from subjects of high knowledge base to low knowledge base, and from subjects of high ability to subjects of low ability. Again, null hypothesis 2 which concerned the number of sub-problems decomposed was rejected by the log-linear analysis. Significant difference was found between the subjects of high knowledge base and low knowledge base.

If pieces of knowledge are viewed as nodes in the networks of organization of long-term memory (Marshall, 1988), then the "underlying factors" in the social science problems can be regarded as nodes in the schema and knowledge structures. Both subjects of high or low knowledge base, subjects of high or low ability had nodes of pieces general knowledge like "land", "labor". However, these nodes might be stored in the form of highly interconnected networks in some subjects, while nodes might be stored as separate fragments in some other subjects. To some subjects, activation of the "factor" nodes might cause activation of the other surrounding nodes, to others, activation of "factors" nodes might cause inappropriate linkage with the others or activation one might not lead to activation of the others.

Social science problems involve daily happenings and common sense phenomena, "factors" and some other general knowledge are stores as nodes in the networks of long-term memory of both experts, novices and laymen. The difference between expert and layman depends on how the nodes of general knowledge are linked and whether appropriate surrounding nodes of domain-specific strategy or domain-specific knowledge can be activated after the activation of these "factors" nodes.

Constraints Identified by Subjects

When the general knowledge is touched, whether then the other surrounding appropriate nodes can be activated. Experts and novices would react differently. When the number of constraints were considered, it was found that high knowledge base and high ability subjects could identify a number of constraints, while the low knowledge base and low ability subjects could not correctly identify the constraints.

Only figure 5.1 and figure 5.3 could constraints be found in the G structure of the protocols. These were protocols of subjects with high knowledge base and of high general learning ability. Constraints could hardly be found in those G structures of protocols produced by subjects of the other groups. Again, null hypotheses 1 and 6 were rejected by the log-linear analysis. Both the diagrammatical representation of the protocols and the statistical testings could well illustrate that difference was found between subjects of high knowledge base, high ability and subjects of low knowledge base, low ability. Furthermore, even hints about constraints, like "it is a kind of labor-intensive industry", appear in the two industrial location problems, subjects, except those of high knowledge base and high ability, could not elaborate these constraints and correctly applied in their problem solving processes.

One of the major findings of the present research is that only those subjects with high knowledge base and of high general learning ability could clearly identify and utilize constraints in the problem solving process. Voss, Greene, Post and Penner (1983) proposed similar notion on the differences between experts and novices in handling constraints. Voss and his associates remarked that experts showed evidence of constraint posting. They noted further that experts handled a constraint before proceeding further with the argument.

Kolodner (1983) distinguished knowledge into two types -- semantic knowledge and episodic knowledge. According to Kolodner (1983), even if a novice and an expert have the same semantic knowledge, the expert's experience would have allowed him to build up better episodic definitions of how to use it. Once the general knowledge nodes about industrial location were touched, experts could build up linkage with the related constraints and use these constraints in further arguments. On the other hand, even the general knowledge nodes of industrial location of novices were called, they could not activate the surrounding nodes in problem solving process. As Gick (1986) put forth that the knowledge of experts, organized into structures, allowed for the effective use of sophisticated strategies that were used badly by novices.

Supportive and reasoning arguments

Similar to constraints identified, greater number of supportive operators were used in the protocols in the high knowledge and high ability group. From the flow diagrams of figure 5.1 to 5.9, it could be found that the number of supportive operators used was obviously greater in figure 5.1 and figure 5.3, while fewer operators were used in the low knowledge groups. Referring to Tables 5.7 and 5.8 showing the cross-tabulation of reasoning structures found in the protocols of the subjects, it was found that the category of high knowledge base and high general learning ability exhibited a remarkable large number. It was therefore found that only those subjects of good performance in Geography could retrieve and link up the pieces of knowledge. These good Geography and high general learning ability performers should be those experienced in the domain and showed more episodic knowledge than the subjects in the other category.

Glaser (1986) suggested that in ill-structured problem solving process, experts work from their memory of relevant information to represent problems and devise arguments for alternative solutions. Moreover, Voss and his associates (1983) noted also that expert problem solver spent a large amount of time on argumentation; while novice protocols were characterized by a lack of argument, weakly supported solution and lack evaluation. The tree diagrams, figures 5.1 to 5.9, reveal that high knowledge, high ability subjects exhibited large number of supportive arguments while low knowledge, low ability subjects displayed much fewer number of supportive and reasoning arguments.

On the other hand, high ability groups, both of high and low knowledge base, showed that they could used greater number of supportive arguments than the low ability group regardless of their knowledge base. Kruskal-Wallis One-way ANOVA revealed that there was no significant difference in knowledge bases among supportive and reasoning arguments at .05 significant level. Results of the Kruskal-Wallis One-way ANOVA were listed in tables 5.29 to 5.32. Reasoning arguments seemed to associate with general learning ability but not knowledge base.

Explanation found in the section named "Constraints Identified by Subjects" may be applied to supportive and reasoning arguments. Greater use of supportive arguments in high ability group regardless of their knowledge base reflected the fact that knowledge bases of the subjects were classified by the Knowledge Test. Knowledge Test consists of questions of factual information only. In other words, only semantic knowledge was used to distinguish the types of subjects. However, episodic knowledge could be useful in further building up of semantic knowledge (Kolodner, 1983). Whenever supportive arguments were used, episodic knowledge, that is, knowledge of application and synthesis, was referred to. As the knowledge bases of subjects were differentiated by only semantic knowledge, it would not be rational to disclose the difference in supportive arguments used with reference to the knowledge bases of the subjects but neglecting the experience and analytical power of the subjects.

Irrelevant Knowledge Bases

The protocols obtained from the subjects of low knowledge base and low ability showed that irrelevant sub-problems and inappropriate supportive arguments were found. Nevertheless, inaccurate information had never been found in the protocols of the high knowledge base and high and medium ability groups. Results showed that novices were not able to evoke the rightful piece of knowledge in solving the problems, while the high knowledge subjects were able to specify fitting pieces of knowledge and isolate the unwanted ones in the problem solving process. Voss, Greene, Post and Penner (1983) mentioned that knowledge of novices seemed to consist of "bits and pieces" of information that were not well integrated. Some of these "bits and pieces" of information about industrial location might be relevant to the problem solving process, but some might not. The appearance of irrelevant information in the protocols of low knowledge and low ability group might be explained by the lacking of the opportunity to organize information in relation to the problem.

Problem solving strategy

From the protocols of the subjects, procedures of solving the problem might be differentiated into two types. These two types of procedures are shown in Figures 5.10 and 5.11. The figures repeatedly show that novices did not have a domain-related strategy as well as an immature knowledge base.

After viewing the question, a subject of low knowledge base or low general learning ability would identify the factors or the sub-problems. Then the subject would propose the solution to the problem immediately, like site A is the solution for relocation. Then, supportive arguments would be put forward in all the factors identified for the decision made in the previous steps. Say site A was decided to be the solution for the site of relocation,

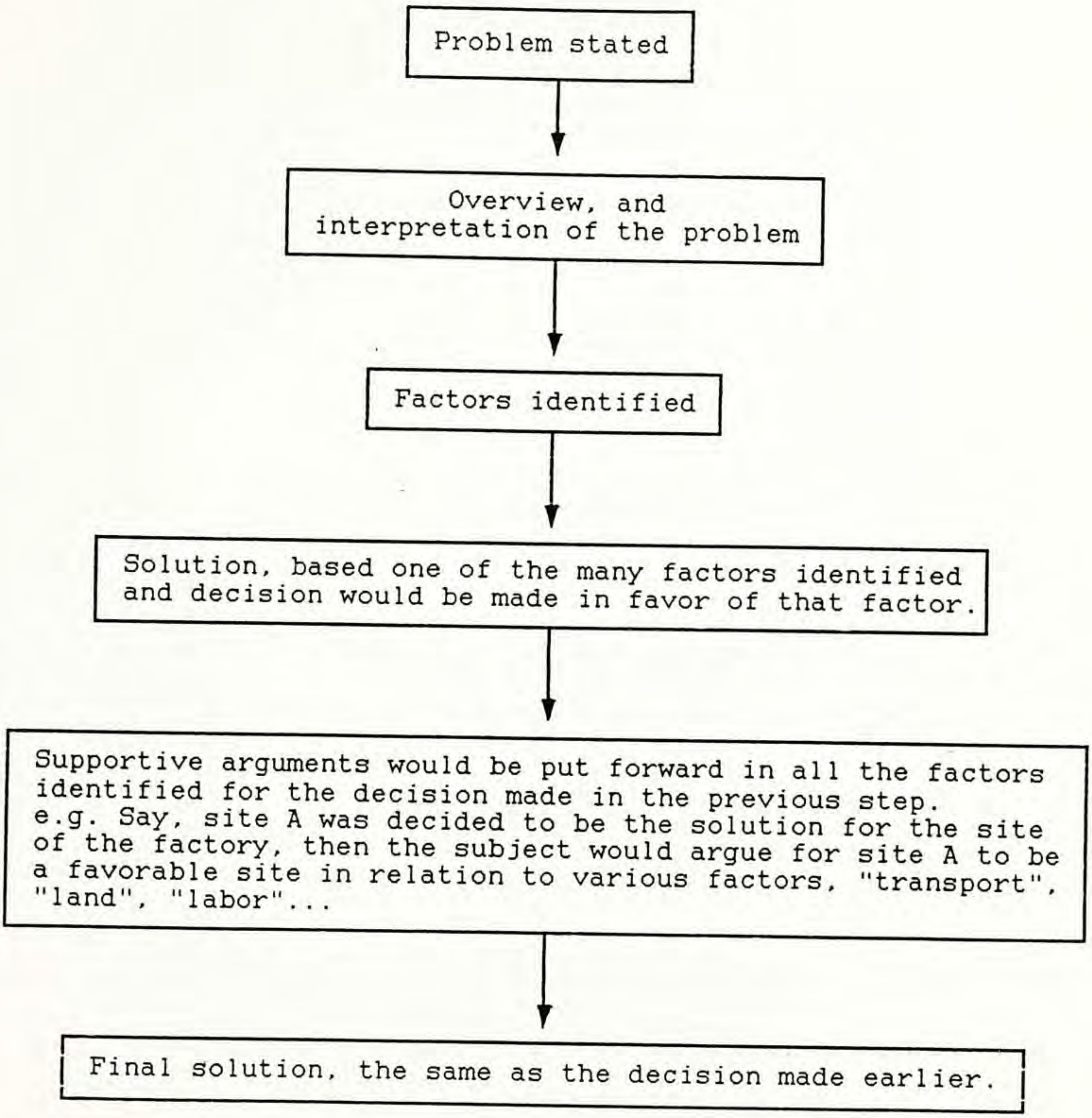

Figure 5.10. Problem solving procedures of a subject of low knowledge base and low general learning ability.

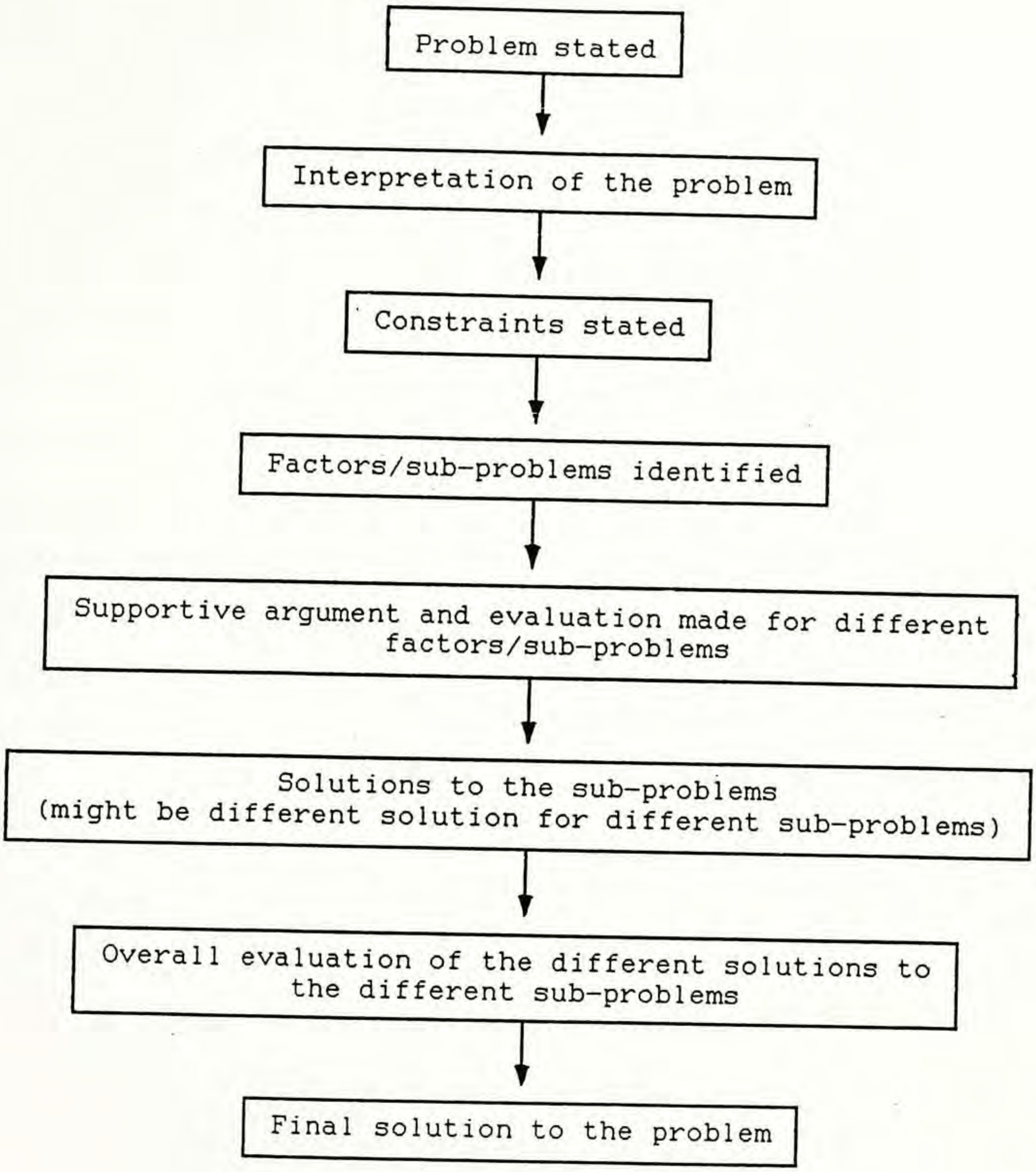

Figure 5.11. Problem solving procedures of a subject of high knowledge base and high general learning ability.

then, the subject would argue for site A to be a favorable site in relation to various factors, "transport", "land", "labor", and so on. The subject would try his best to extract pleasing arguments for site A with reference to the factors.

On the other hand, subjects of high knowledge base and high ability would start solving the problem by interpreting the problem and stating the constraints relating to the problem. Then, a subject would identify the factors governing the problem, that is, decompose the problem into sub-problems. A subject would bring out supportive argument and evaluation for different sub-problems, then, put forward solutions to sub-problems. A subject might bring different solution to different sub-problems. Overall evaluation of the different solutions for the different sub-problems would be made. Lastly, the final solution to the problem was made.

The findings about the difference between the high knowledge, high ability group and the low knowledge, low ability group in this study go parallel with the idea brought by Voss, Greene, Post and Penner (1983). Voss and his associates (1983) noted that experts showed constraint posting in the problem solving process, and, handled sub-problems one by one before proceeding to the final conclusion. Voss and his colleagues further remarked that the problem spaces established by the novices appeared to be quite limited. Because of the limitation of problem space revealed by the low knowledge and low ability subjects, they viewed the problem from only one of the factors, made their solutions before complete evaluation and overall consideration. Chi and Glaser (1985) presented a corresponding idea on the ill-defined problem solving strategy. It was found that both experts and novices used the strategy of decomposition of problem into sub-problems. However, the differences were that the experts tended to create a number of general sub-problems that might encompass several related causes, whereas the novices related solutions very directly to individual causes.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

The purpose of this study was to determine if problem solving performance in social sciences varied with domain-specific knowledge regarding general learning ability. This chapter discusses the relevance of the findings of this study to the research questions and to the literature. Conclusions and recommendations based on the research data are presented.

CONCLUSIONS

The results of this study suggest three major conclusions which support current trends in the studies of social science problem solving performance. This study provides evidence, firstly, that experts know more about the domain and can access and use their knowledge more efficiently than the novices. Though the semantic knowledge of the domain, that is, the nodes of pieces of factual knowledge of the domain, may not vary from experts to novices, the episodic knowledge of the domain permits the experts to link and evoke the relevant and appropriate interconnected nodes of knowledge in the problem solving processes. Such conclusion supports the finding of Voss and his associates (1983), Marshall (1988) and Reimann and Chi (1989).

Secondly, the ways of handling and solving problems in relation to the problem representation, constraints and reasoning arguments by subjects in this study exhibited a similar picture the one uncovered by Voss, Greene, Post and Penner (1983). Voss and his co-workers pointed out that social science domain experts developed their representations in problem solving by adding a lot of domain-specific constraints to their representation of the problem. In addition, experts exposed an extensive arguments in the form of supportive operators and reasoning structures in the problem solving process.

Thirdly, there continues to be evidence that the strategy in problem solving varies from experts to novices. Although, problems in social sciences are usually ill-structured, strategies employed in mathematics will not be applicable to social sciences, experts are still able to apply the procedural knowledge they have in solving problems. Such strategies may not be as clear cut as those in mathematics, experts in social sciences may retrieve the clear stepwise domain-related procedures form the knowledge-and-schema system in problem solving. On the other hand, novices follows a rather confusing path in executing the solution.

IMPLICATIONS

Through the study of social subjects, like geography and economics, secondary students should become aware of a range of issues and problems on a variety of scales from local to world scale which they are able to evaluate and to seek answers for the problems. The Curriculum Development Committee in Hong Kong (1984) highlighted that Form 5 leavers, on completion of the course of geography, should be able to understand geographical concepts and ideas, and apply them to show an understanding of problems on a variety of scales. This research revealed that ideas or pieces of knowledge were found in students of both high and low general learning ability, however, the connection of the pieces of knowledge, the application of these pieces of knowledge and the strategies employed in solving the problems varied from the high ability group to the low ability group. It is suggested that organization and linkage of pieces of knowledge should be emphasized, and experience in problem solving should be included within the teaching program in social subjects in secondary schools.

Moreover, recent curriculum changes in public examinations of geography in United Kingdom have focused more directly on the development of appropriate decision-making skills to resolve people-environment problems. A lot of textbooks and exercise books (Law & Smith, 1987; Cowlard, 1990) on problem solving have published in recent years. These recently published textbooks in United Kingdom provide a lot of situations and case studies for students to make decision and to solve problems. On the other hand, Cowlard (1990) even suggested methodology and selection of appropriate techniques in solving problems. He introduced a stepwise systematic approach to geographical decision-making. His approach followed the broad pattern -- "PROBLEM---> EVIDENCE ---> ALTERNATIVES ---> DECISION". Such approach corresponds to the problem solving control structure model as mentioned in chapter 3. The ability of students in application of concepts to problem solving will be improved if they can make use of the strategies learnt from textbooks or classroom teaching through the practice of simulated case studies. Nevertheless, problem solving strategy does not appear in any of the existing geography textbooks in Hong Kong.

Two major approaches of teaching-learning process were recognized (Curriculum Development Committee, 1984). In order to develop students' problem solving ability, the teaching-learning strategies should shift from thinking deductively to thinking inductively. Often students of low learning ability do not have the necessary background or maturity to argue from the general to the particular. They do not have the required connections among the pieces of knowledge. The "thinking deductively" approach, that is, to work from some theoretical idea which is then illustrated by reference to an example, may not be beneficial to the low ability group. On the other hand, "thinking inductively" approach asks students to work from some features in the environment, to analyze the factors and processes which might explain its nature, and from this explanation to derive a theoretical idea in conclusion. Such approach encourages students to start from the pieces of knowledge, then advances students to establish linkage between these pieces of knowledge and to come to a conclusion. In other words, "thinking inductively" approach goes parallel with the way of problem solving in social sciences. The analytical and synthetic power of the students may be improved through "thinking inductively" learning.

LIMITATIONS

Some of the limitations envisaged in the present study are as follows.

1. The applicability of the industrial location problem solving performance to the world of social sciences may be limited, since industrial location is only one of the many topics in social sciences.

2. It is difficult to explore, in detail, the knowledge structure of subjects. The method used in categorizing subjects into different knowledge groups was a rough and crude one. Again, the way used in determination of the subjects' ability might be quite restricted.

3. All the instruments employed for this study were developed by the author and had never been used before. Instrumentation might be a source of internal invalidity.

4. The sample for this study was small as it involved only 30 subjects and two schools in Hong Kong. Hence, generalization of findings to the whole population should be cautiously exercised.

RECOMMENDATIONS

Based on the limitations of the study, the following recommendations were formulated.

1. The study should include problems of other topics in social sciences, like urbanization problems.

2. Since the Knowledge Test in this research was a test of factual knowledge, tests for knowledge of higher levels should be devised and include in the study of domain-specific knowledge.

3. The study should be replicated with a larger sample to prevent small cell sizes.

4. The study should be replicated in different geographic areas.

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*** *** *** ***

A P P E N D I X 1

T H E K N O W L E D G E T E S T

~~~~~~

<u>INSTRUCTION TO CANDIDATES</u>
The time allowed is 25 minutes.
Answer **ALL** questions.
Put **ALL** your answers on the Multiple Choice Answer Sheet provided.

~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~

1. Manufacturing means
   A. provide raw materials from nature.
   B. provide services to the community.
   C. change raw materials to products
   D. change services to useful products.

2. Which of the followings are factors affecting the location of a factory?
   1. power
   2. water supply
   3. climate

   A. 1 only
   B. 1 and 2 only
   C. 2 and 3 only
   D. 1, 2 and 3

3. Industries which require special raw materials tend to be located near
   A. the source of raw material
   B. the market
   C. the source of power
   D. technologically well developed areas

4. Raw material-oriented industries are industries which
   A. use more than one kind of raw material.
   B. use only one kind of raw material.
   C. require raw material that can be found everywhere.
   D. are highly attracted to the raw material sites.

5. Factories in industries using raw materials that have a high weight-loss ratio (that is, product is lighter than raw materials) in processing are located close to the sites of
   A. supplies of raw materials.
   B. supplies of power.
   C. market.
   D. mid-way between the source of raw material and the source of power.

6. Power-oriented industries are those industries where
   A. power supply is as important as supplies of raw materials.
   B. power supply comes from various sources.
   C. power supply is the most important locational factor.
   D. there is substitution of power resources.

7. Those large-scale industries which need space for construction, storage require
   A. available transportation facilities.
   B. plenty supply of labour.
   C. extensive, flat lowland.
   D. good port facilities.

8. Labour-intensive industries are attracted by
   A. large quantity of cheap labour.
   B. the supply of skillful labour.
   C. the high level of technological development.
   D. high standard of living of labour.

9. Labour supply for industries depends on
   1. level of unemployment
   2. level of standard of living
   3. number of population between ages 15 and 65
   A. 1 and 2 only
   B. 1 and 3 only
   C. 2 and 3 only
   D. 1, 2, and 3

10. The supply of skillful labour is affected by
   1. the educational level
   2. the degree of literacy
   3. presence of research institutions
   A. 1 and 2 only
   B. 1 and 3 only
   C. 2 and 3 only
   D. 1, 2 and 3

11. Technology-oriented industries are industries which require
   A. power, raw materials, labour and capital.
   B. modern technological skills.
   C. modern means of transport.
   D. labour with high standard of living.

12. Factories producing highly perishable goods would like to locate near
   A. source of raw material.
   B. source of power.
   C. place with plenty supply of labour.
   D. market.

13. In order to save transport costs, factories producing products which have a ....?.... tend to locate near their markets.

A. high volume or weight
B. small volume and weight
C. high volume but light
D. small volume but heavy

14. Factories which produce fragile goods would like to locate near

A. places with good transport facilities.
B. sources of raw materials.
C. places with the supply of skillful labour.
D. market.

15. Industries with bulky raw materials or products often locate along the coast. It is because

A. cheap water transport is available.
B. the requirement by government.
C. cheap land is available.
D. extensive lowland is available.

16. Road transport is efficient for the distribution of ...?... materials over short-haul distance.

A. large volume
B. heavy and bulky
C. bulky
D. less bulky

17. Which of the following statement is CORRECT?

A. Complex and large industries are often attracted to advanced countries which have surplus capital.
B. Complex and large industries are often attracted to developing countries which have limited capital.
A. Small-scale industries are often attracted to advanced countries which have surplus capital.
A. Small-scale industries are often attracted to developing countries which have surplus capital.

18. The direct role of government in the location of industries includes

1. town planning
2. decentralization policy
3. tariffs

A. 1 and 2 only
B. 1 and 3 only
C. 2 and 3 only
D. 1, 2 and 3

19. Which of the following industries are less likely to relocate even when their former locational pulls are lost?

1. Industries which require plenty labour.
2. Industries with long history of development.
3. Industries which are of very large scale.

A. 1 only
B. 2 only
C. 1 and 3 only
D. 2 and 3 only

20. What is meant by the term "footloose industry"? This means that the industry

A. has a relatively free choice of location.
B. has no choice on location of factory.
C. would be located on a site planned by the government.
D. has only one alternative on the choice of location.

21. Labour is an important factor to industries because of two significant factors. These two most important factors are

1. skills of labour.
2. standard of living of labour
3. cheapness of labour
4. ages of labour

A. 1 and 4
B. 2 and 3
C. 1 and 3
D. 2 and 4

22. The three things about the environment that must be considered when a factory site is being chosen are

1. the land (that is, the relief)
2. the drainage (whether it will flood or not)
3. the cost (the rent or the value of the land)
4. the beauty (nearness to country park, beaches)

A. 1, 2 and 3
B. 1, 3 and 4
C. 2, 3 and 4
D. 1, 2 and 4

23. Different industries are set up in different places within the city, because different industries have different abilities to pay

A. wage.
B. rent.
C. the cost for raw materials.
D. the cost for power supply.

24. Which of the following factors is most important in the initial setting up of a factory?

A. wage
B. capital
C. payment for electricity
D. payment for raw materials

25. Which of the following mode of transport is most suitable for bulky products?

A. Road transport
B. Air transport
C. Water transport
D. Container transport

* * * * * END OF TEST * * * * *

APPENDIX 2

LOCATING A BALL-PEN FACTORY

WHAT TO DO?

Suppose you were the managing director of the firm Lion Co., maker of quality ball-point and felt-tip pens. You are going to move the plant from the largest city of the country, where it is located, to the northern part of the country. The factory can be re-located on site A, B or C, shown on the accompanying map. Note, you have to pay attention to what type of industry it is. Is it a kind of labour-intensive industry (勞工集約工業)? Does the industry undergo great weight loss (減重) or no weight loss?

By studying the map and the given information, considering the nature and type of industry, and the special requirements, examining the conditions of each site, recommend one of the sites you consider the best choice for re-location. Why would you recommend such site? Give, in details, reasons for your choice. In your answer, you should bring out at least three major points, with detailed explanation, illustrating the choice of location of the factory. Write at least two pages.

INFORMATION

The firm

It is located in City L, the largest city of the country. The country is an island country, however, many of the large towns and cities are not located at the coast. Furthermore, the country is a developed industrialized country. The firm is expanding slowly in the national market with ideas of exporting products to nearby countries. There are about 200 workers totally. About 50 are executive (行政人員), office staff, and key skilled workers who will move from City L, where the factory is now located. The rest of the labour will be re-cruited locally (從本地招聘) in an area of high unemployment. The present site in City L is 6,000 m^2.

Please be noted that firms setting up in development areas (發展地區) shown in the accompanying map will receive a grant (撥款) for 50 per cent of removal costs and 22 per cent of the cost of new building and equipment.

Sites

A – It is 50,000 m^2. It is located 8 km from the village of

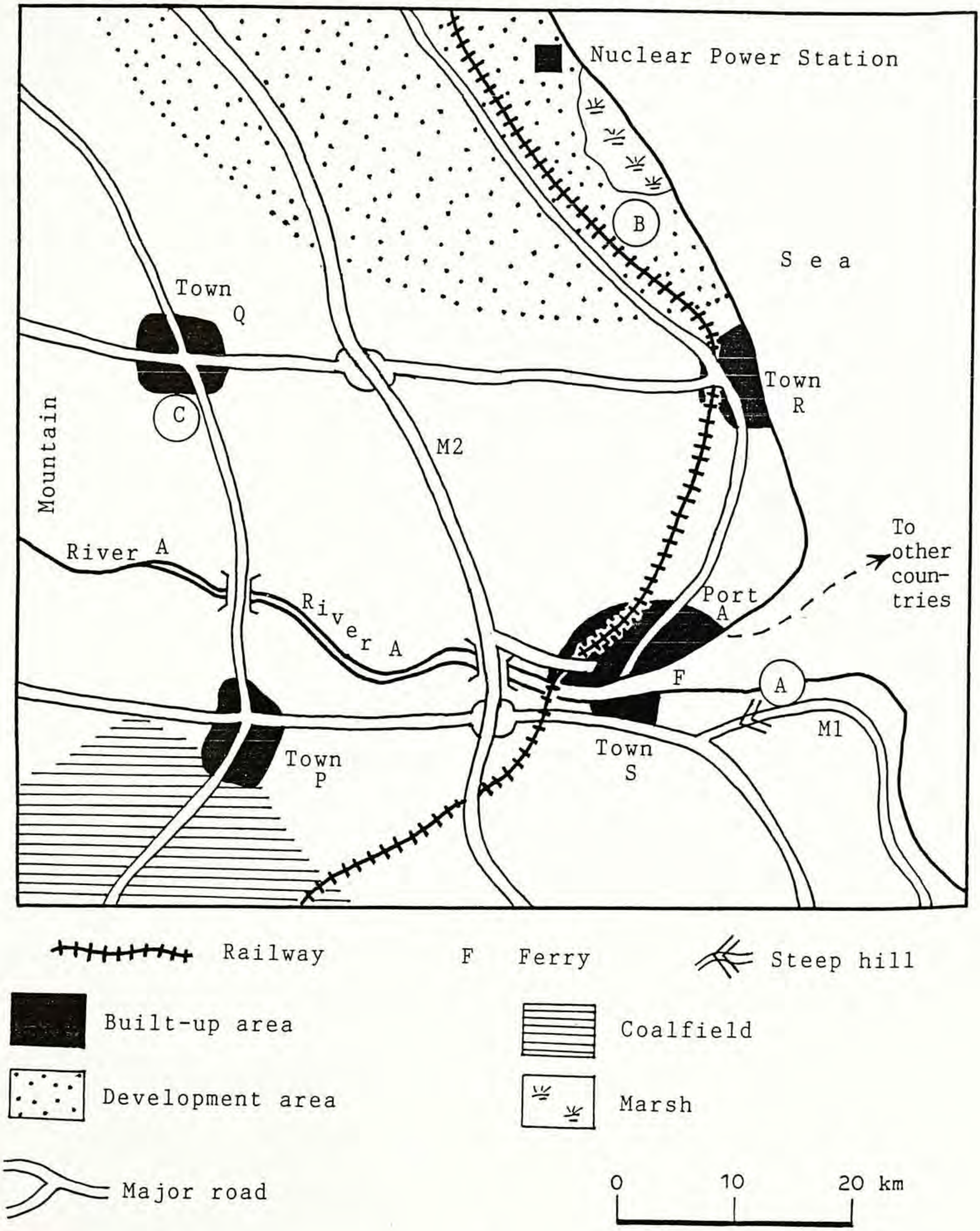
Town S and within easy reach of Port A via ferry. (Note, the distance between Yau Ma Tei MTR Station and Mongkok MTR Station is about 0.8 km.) Access is restricted (限制) due to the 1 in 5 gradient on the M1 motor road. It is a windy site in the beautiful countryside with views over the estuary (河口灣) of River A. No public transport passes the site. There are restrictions on further residential (住宅的) development around Town S.

B - It is an area of 16,000 m^2 with possible extension of further 12,000 m^2 on marshland (沼澤) which would have to be drained (排水). It is situated 8 km north of Town R, a small resort with serious lack of employment opportunities during winter, especially for female labour engaged in the tourist trade in summer. There are regular bus services from Town R and Port A. Moreover, areas earmarked for residential expansion around Town R are found.

C - It is 12,000 m^2. The site is situated 3.5 km to south of Town Q, a smart town with an old university and castle. There is high male unemployment in the area due to declining coalfield to south. Area to the south is dominated by dirty mining villages, but to the west is an enjoyable open country in mountainous area. The rapid access to the highway M2 gives good communications with Port A and rest of the country. There are regular bus services to Town Q and Town P. There are abandoned (棄置) houses in the mining villages, but no new housing is planned in the area.

< GO ON TO THE NEXT PAGE FOR THE MAP >

MAP FOR "LOCATING A BALL PEN FACTORY"



APPENDIX 3

LOCATING AN OIL REFINERY

WHAT TO DO?

Suppose you were the managing director of Tiger Company, a petro-chemical company (石油化公司). Crude oil (原油) and gas, which are obtained from the oilfield (油田) at the sea, form the major raw materials for the oil refinery (煉油廠). The crude oil and gas are refined (提煉) and made into various products including chemicals. Moreover, refined oil is one of the major sources of power for the industries in this area of study. You are going to build an oil refinery in the area. The firm's surveyors (測量員) selected four possible sites - A, B, C and D. Information about the oil refinery and the four possible sites is given below.

By studying the map and information given, considering the nature and type of industry, and the special requirements, examining the conditions of each site, recommend one of the sites you consider the best choice for the location of the oil refinery. Why would you recommend such site? Give, in details, reasons for your choice. You must include at least two major points with detailed explanation in your answer. Write at least one page.

INFORMATION

1. Such industrial landscape is one of pipes, tanks, tall chimneys and strange-shape towers. Most urban dwellers dislike such landscape.

2. Petroleum refining (石油提煉) does not involve weight gain or loss (重量增加或減少). Virtually all the products can be used.

3. Crude oil may be transported to the site by oil tanker (油輪) or through pipelines (油管).

4. The sea floor is found to be suitable for the construction of pipelines.

5. Extensive area (廣闊的地方) is required for the development of the plant.

6. Build-up areas in the map are sources of labour force.

7. Further information about the four sites and their environment is given in the map.

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MAP FOR "LOCATING AN OIL REFINERY"